1994

The Impact of Advanced Information Technologies on Architecture and Engineering Design Firms: A Field Study

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December 1994

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A dissertation submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy at
Virginia Commonwealth University

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Acknowledgments

In the immortal words of Thomas Merton, "no man is an island." These words are an appropriate metaphor for the doctoral degree process. Without the help, influence, and support of numerous individuals, no student is likely to successfully complete the doctoral degree since it requires more than just academic acumen and stamina. This has been particularly true in my case, since all of my academic endeavors were completed on an essentially part-time basis. Therefore, I would like to thank some of those individuals who were collectively responsible for my achievement of this lifelong goal.

My supervisors and managers at Philip Morris, USA provided me the opportunity to pursue the doctorate degree with their support of my academic goals. A few of these individuals are: J. V. Bellamah, F. L. Bullock, A. S. Church, S. E. Clark, K. A. Gammon, R. C. Kistler, J. L. Miller, and L. X. Nghiem. To G. H. Bryant, B. M. Evani, W. B. Garner, and other engineering colleagues and associates, I remember the additional motivation I gained by your expressing sincere interest in my academic endeavors. To these associates, and many others, I am appreciative of your having faith in my abilities even when I did not.

I am especially indebted to my doctoral dissertation committee for their guidance and encouragement that lifted my spirits whenever I became disheartened, and for their caution and correction whenever I became overconfident. In particular, I would like to thank Dr. Julian W. Riehl, for his constant generosity in sharing his time and knowledge as my doctoral advisor and his superb coaching and navigational skills through the shoals of dissertation research; Dr. Richard J. Coppins, for his pragmatism and clarity of thought; Dr. Bartow Hodge, for his counsel, depth of understanding, and experience; Dr. Eugene H. Hunt, for his constant encouragement and friendship, and for sharing his views on the doctoral "process;" and Dr. D. Robley Wood, Jr., for his insightful observations and helpful suggestions for conducting the research. I am also indebted to other faculty members in the School of Business for the opportunity to study and question the serious matters of information and management in its various business settings.

My sincerest appreciation is due also to the distinguished experts who served on the Delphi panel for giving generously of their valuable time, knowledge, and experiences: These individuals actively contributed their time and experiences in developing and refining the research questionnaire used for the field research: Thomas F. Arant; Elizabeth Bollinger; A. B. Cleveland, Jr.; Michael R. Hough; Robert J. Humphrey; David A. Jordani; Thomas M. Koulopoulos; Robert B. Mills; Joel N. Orr, Ph.D.; Larry G. Richards, Ph.D.; William Saffady, Ph.D.; Richard N. Stover; and Eric D. Teicholz: Your participation was critical, irreplaceable, and made the dissertation research meaningful and relevant.

I am also in debt to the architects, engineers, designers, and managers in the firms visited for the field research for sharing their opinions, thoughts, and insights into a complex and chaotic information revolution that has forever changed the architecture and engineering design professions. I share a common concern with them for what the future holds for practitioners of the disciplines.

Lastly, I would like to dedicate this dissertation to my loving and loyal wife, Becky, and to my sons, Barry and Steven, both Eagle Scouts, of whom I am very proud. Their sacrifices and understanding (and tolerance whenever they did not) of my academic goals can never be measured, but only partially repaid with my gratitude and love.

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INTRODUCTION

Chapter Objective

The objective of Chapter 1 is to present the need and justification for the dissertation research. The research objective and research question are presented in addition to the significance and limitations of the research.

Need for the Research

Architecture and engineering (A&E) design firms have experienced rapid changes due to the introduction of advanced information technologies (see Note). Work processes in these firms have been transformed from primarily manual methods of processing data to highly automated activities that utilize advanced information technologies. The very texture of architecture and engineering design practices has changed because of the introduction of advanced information technologies (AIT). The effective implementation of these technologies, however, has been erratic and sometimes disorganized, even among firms that have adequate resources to accommodate rapid technology changes.

Note: "Advanced information technologies" as defined by Huber (1990) will be used in the dissertation, instead of the often-used phrase, "computer-based information technologies." See Appendix J for a complete definition.

In recent years, a primary concern of the architecture and engineering design services industry in recent years has been to operate effectively within a declining domestic market for these design services. Many firms have been unable to accommodate the complexities of managing advanced information technologies. Those firms that have been able to plan and incorporate AIT into their businesses have had to contend with normal operations concurrently with the critical acquisition and implementation activities required for effectiveness and efficiency.

There appears to have been little research in the A&E design services industry to assist management in successfully integrating advanced information technologies. Knowledge of the proper integration approaches seems to be primarily derived from anecdotal experiences from engineers and managers who learned while doing. Since knowledge and experience of the integration of advanced information technologies are generally lacking among managers and engineers, implementation appears to be characterized by purchasing and training efforts. Attention to integration activities appears to have been deferred or avoided in favor of activities that are more tangible, discrete, and less complex.

Therefore, a fundamental problem facing architecture and engineering firms is the lack of research concerning the effective integration of advanced information technologies in engineering design. The dissertation research examined what the impact of advanced information technologies has been on competent architecture and engineering design firms. Empirical data were collected concerning how these firms have conducted planning, acquisition, and integration of various advanced information technologies into their architectural and engineering design services.

Research Objective

The research investigated architecture and engineering design firms that have a reputation for being competent in the utilization of advanced information technologies. It is believed that competency in the use of these technologies has contributed to the ability of A&E design firms to perform engineering design services effectively and efficiently.

Review of the literature suggests that the use of advanced information technologies has had lasting interactive effects on the strategy, structure, management, tasks, and the personnel of organizations. There does not, however, appear to be any dissertation research on the impact of advanced information technologies on architecture and engineering firms. The research conducted addressed critical questions relating to the effective integration and use of advanced information technologies that face firms conducting design services in the A&E industry.

The objective of the research was to determine the impacts that advanced information technologies have had on A&E design firms and to determine if those impacts have been favorable or not. Additionally, a group of "competency" indicators was developed as part of the research. This list of indicators or factors of competency can be used by managers and engineers in the industry to qualitatively assess their individual firms in terms of effective utilization of advanced information technologies.

Research Question

The basic question for the dissertation research can be stated as:

> What has been the impact of advanced information technologies on architecture and engineering design firms, and to what degree have competent architecture and engineering firms implemented advanced information technologies into their design services?

The field research focused on identifying the distinct characteristics that competent architecture and engineering design firms possess or exhibit in the utilization of advanced information technologies.

The ability to integrate and utilize advanced information technologies should have substantial impacts within A&E design firms. Presumably, these impacts have been positive, although much of the research to date indicates mixed conclusions in this respect. It is believed, however, that competent A&E design firms have an identifiable set of distinguishing factors that relate to the effective utilization of advanced information technologies for providing valuable engineering design services.

Other secondary research questions, designed to investigate the various concepts of the impact of advanced information technologies, were proposed and developed by using a group of experts in a Delphi process. The research questions that were developed by using an expert Delphi panel are provided as Appendix G. The administration of the Delphi process is discussed in Chapter 3.

Significance of the Research

The introduction of various advanced information technologies into architecture and engineering design firms has led to a multitude of management and technical integration problems. The traditional methods of creating, distributing, and storing technical information, although still in use, are being abandoned in favor of computer-based methods. Many engineering firms that have acquired newer information technologies, however, have experienced substantial difficulties in the implementation and integration of these systems.

In the past two decades, architecture and engineering design has been drastically altered by the introduction of word processors, computer-aided design (CAD) systems, information data bases, electronics documents management, digital scanning, and electronic workflow systems. To date, there has been little research to address the problems that face engineering design firms concerning the acquisition, implementation, and effective utilization of newer, advanced information technologies. Research literature for improving the process of integration of advanced information technologies into the operations of architecture and engineering design firms is almost nonexistent. There appears also to be little formal research and analysis of why these technologies have been acquired, why they are beneficial compared to traditional engineering design tools, and what the future is for A&E design firms that can successfully acquire, implement, and integrate advanced information technologies.

Review of the literature indicates that the introduction of computer-aided design systems has often resulted in counter-productive activities that have resulted in information management and control problems for many firms (Robertson and Allen, 1992). Brynjolfsson (1993) discusses the productivity paradox of information technology and the apparent counterproductive benefits derived by its implementation. There is substantial documented evidence that large financial investments have been made for the acquisition of various computer-based information technologies (Brynjolfsson, 1993) and yet, in the services industries, productivity of so-called white collar workers has actually declined (Roach, 1987).

Studies predicted that the estimated market expenditures for computer-aided design, engineering, and manufacturing systems would reach $7.7 billion in 1991 and would exceed $25 billion by 1995 (Daratech, 1990). However, there appears to be little documented, empirical evidence that these investments have been profitable or productive for the engineering design process. Debate over the benefits of CAD systems continues (Farrar, 1987). Evidence is inconclusive regarding the effectiveness of the investments in advanced information technologies currently being acquired and used in architecture and engineering design firms.

Tested theories for analyzing or assessing the impacts of computer-based information technologies on organizations are absent from the literature. Regarding the use of information technologies in organizations, Steinfield and Fulk (1987) lament that "there has been little synthesis, integration, and development of theoretical explanations [and] that it is time for theory development and theory-guided research." Although advanced information technologies are becoming more prevalent in organizations, their relatively recent appearance and rapidly changing characteristics have caused confusion for administrators and advisors in anticipating and planning for the impacts they may produce (Huber, 1990). Additionally, Huber believes that due to the recent introduction of advanced information technologies, experience is lacking and, therefore, the value of a sound theory would be considerable. The primary issues raised by Huber address the critical characteristics of advanced information technologies that impact organizational design, intelligence, and decision making, and how these impacts are different from utilization of more traditional technologies.

The research conducted analyzed the effects of advanced information technologies on architecture and engineering design firms that are believed to be effectively utilizing advanced information technologies. Investigation of how advanced information technologies have been

integrated into the firm's operations was a key consideration. Research dealing with the acquisition, implementation, and effective utilization of advanced information technologies will benefit future managers and practitioners of architecture and engineering design.

Limitations of the Research

The research was restricted to six architecture and engineering firms whose individual annual revenues exceed $30 million and with a corporate or major regional office in the eastern United States. The field research included only six A&E design firms because of financial limitations and access to regional or corporate offices in the eastern United States. Therefore, generalizability of the research conclusions is restricted to the general category of large A&E design firms utilizing advanced information technologies, although some of the research findings and conclusions may be applicable to other A&E design firms as well. Geographical location does not appear to be relevant for purposes of the dissertation research.

A limitation of the study was that encountered in any business case scenario; that is, the difficulty of obtaining useful and valid information from a specific organizational environment by interviewing a relatively small number of personnel. Each individual A&E design firm visited utilized slightly different combinations of advanced information technologies and in different applications. However, there were common features among the six firms of the use of advanced information technologies in architecture and engineering design. The approach and conclusions of the dissertation research should be applicable to any A&E design firm using advanced information technologies.

Financial analysis considerations were not included in this research due to the general proprietary nature of the A&E design services industry. Many, if not most, of the large A&E design firms are private corporations and do not publicly disclose earnings and other key financial data. There is also the danger of deriving causal inferences of "success" in terms of financial profits and growth. For example, in a declining national and global market for engineering services, it would be erroneous to conclude that the use of advanced information technologies somehow resulted in decreased annual billings and net profits just as it would be

erroneous to infer causality between the use of AIT and profitability in an increasing market for engineering design services, whenever profits are typically increasing.

Research Background

In the space of twenty-five years, engineering design methods have been affected by the application of computers and engineering information data bases. The introduction of word processing and computer-aided drafting technologies was just the forerunner of other advanced information technologies: computer networks, digital scanning, computer-output microfilm (COM), relational and object-oriented data bases, and a large array of information storage technologies.

Within the engineering design environment, the introduction of computers focused first on automation of manual tasks. For example, word processing was perhaps the earliest microcomputer-based information application within engineering firms. Later, the introduction of computer-aided drafting systems began to change the manner in which engineering drawings were produced. Later still, computer-aided design (CAD) systems began to provide the engineer with tools that virtually changed the manner in which traditional engineering design and analysis is performed.

Until the development of CAD systems, engineering design tasks and activities were accomplished by a cadre of drafters, designers, engineers, and project managers. Most of the information was conveyed by paper or paper-like media. Communications were conducted largely by project review conferences and team-oriented activities. Information that needed to be preserved or communicated was typed or hand-written. Mathematical computations were performed by manual methods or by reference to tables of parameters compiled by experimental methods. Drawings and sketches were produced by legions of drafters, reviewed by designers or engineers, modified, and subsequently approved. The amount of time required for engineering designs was long, unpredictable, and costly. Complex engineering designs were costly and risky, even if simple models or prototypes could be constructed. Not infrequently, costly construction delays would be encountered due to engineering design or documentation problems, further adding to the cost of design and ultimately to the total project costs.

The earliest computer-based engineering applications were performed on large mainframe computers. These applications included financial billing, project management, and resource tracking. More sophisticated applications included material simulations and engineering analysis of mathematical expressions. With the introduction of the personal computer (PC) in late 1981 and the beginning of distributed engineering information and computer processing on a corporate scale, an information revolution of the engineering process began, first with basic 2D computer graphics, then more complex 3D graphics and solids modeling, and later still, with information data bases.

The complexity of the engineering design process has been further complicated by the introduction of advanced information technologies that must be integrated with legacy (existing) systems, which have been in use for several decades. The difficulty of managing, tracking, and retrieving the "correct" engineering drawing has become even more complex due to the number of media forms used for drawings. For example, prior to the use of computers, engineering drawings were usually produced first on vellum or mylar, and later archived on microfilm. In today's environment, the same drawing can exist in vellum, mylar, or microfilm form, as well as the computer-based magnetic form. The introduction of scanning devices has produced yet another form of imaging for drawings and other design documents, requiring even more indexing of architecture and engineering information.

Due to initial acquisition costs, as well as increasing on-going operating costs, some architecture and engineering design firms have not been able to incorporate advanced information technology at a pace to successfully compete with their competitors. Associated with the general decline in the need for engineering design services at the national level, A&E design firms in the future will face increased pressures from those firms who can successfully implement and integrate advanced information technologies into their engineering work processes.

Virtually all engineering design processes have been computerized to date, including project management. Along with this technology revolution in the engineering design services industry, additional changes have also changed the engineering supplier industry. The use of drafting tables and other predominantly paper-based engineering design tools and instruments has become the exception, having been displaced by engineering workstations and personal computers. Other indicators of change associated with the introduction of advanced information technologies into A&E design firms are:

- shifts in decision-making responsibilities from line management to designers and engineers,
- training and retraining of engineers and technicians,
- elimination of various clerical tasks,
- combining of documents functions and engineering functions,
- combining of secretarial functions and engineering functions,
- reduction of time-to-design and time-to-market,
- improvement in the quality of engineering designs,
- improvement in engineering productivity,
- improvement in engineering services profitability,
- use of electronic spreadsheets,
- dependence on electronic data bases,
- use of finite element analysis,
- use and development of 2-D, 3-D, and virtual reality products.

These changes have resulted in numerous organizational and management problems for A&E design firms. Some of these problems are:

- difficulties in integration with existing, legacy systems,
- changes in work flows and procedures,
- complexity of computer systems,
- high initial acquisition and operating costs,
- dependent on a well-trained, computer-literate engineering cadre,
- requires computer-literate support personnel,
- organizational friction and a shift in the control of information and power.

Nearly all vendors in the A&E drafting products and supplies industry have been displaced by a smaller number of computer graphics manufacturers and vendors. Following the plight of slide rule manufacturers, the manufacturers of traditional engineering design tools have virtually disappeared and have been replaced by numerous suppliers of computer-aided design hardware, graphics-oriented software, data base software, and a host of related information-handling technologies. As more and more engineering functions are performed by computer-based applications, the requirement for effective information systems and supporting technologies will increase.

The functions and tasks of engineering are, however, difficult to replicate with computer-based automation. "Engineering design is complex and communication-intensive work" (Robertson and Allen, 1993). The introduction of computers into the engineering design services environment has contributed to even more complexity and more communication-intensive engineering activities.

The researcher believes that the texture of engineering organizations has been altered to accommodate the adoption of advanced information technologies. Early changes in the engineering design process began with the introduction of word processors. Followed by widespread adoption of CAD systems, procedures for effective electronics document management have been subsequently affected in ways that were not foreseen.

Not only organizational and management changes have been necessary, but also changes in the engineering process have been necessary. These changes have presumably been positive ones, although not without producing internal organizational stresses. No longer does an engineer work in constant association with other engineers and designers. With the variety of advanced information technologies now available and required, design engineering has become a more isolated function, one requiring mastery of complex computer environments and the ability to utilize those technologies effectively toward the accomplishment of business objectives.

Additionally, with the increasing utilization of computerization and magnetic media, the texture of the engineering information environment is changing rapidly from a tangible one to an invisible one. Locating and retrieving engineering project and design information from computer-based sources has become more critical as reliance upon legacy systems that emphasized paper-like storage media diminishes in importance. The information environment of engineering design in the early 1990s is characterized by multiple data locations, multiple types of media, and potentially inaccurate data because of loss of revision control. Infrastructures that supported the paper-oriented procedures have not been easily modified to accept the incorporation of advanced technologies. In some instances, the formal discipline of standard engineering practice has been eroded by the independent ability of designers and engineers to produce "finished" work, without the rigid requirement of obtaining design reviews and approvals.

Many engineering design firms are now involved in migrating from manually oriented design methods to advanced information technologies, like CAD and optical scanning. A new set of information problems has resulted that requires careful orchestration of the newer information technologies and, at the same time, continuation of operations and support for older, less-automated information technologies, like microfilm and microfiche-based systems. Adding digital imaging and scanning technology to the realm of engineering information has resulted in further complexity within the engineering disciplines.

Chapter Summary

In summary, it is believed that the impacts of various advanced information technologies have resulted in important and permanent changes within architecture and engineering organizations. The research study conducted addressed these impacts for six architecture and engineering firms competent in their implementation and utilization of advanced information technologies. Chapter 2 presents a synopsis of relevant research and literature on advanced information technology and its impacts on organizations.

CHAPTER 2

LITERATURE REVIEW

Chapter Objective

The objective of Chapter 2 is to present a summary of the published literature relevant to the dissertation research. A synopsis of doctoral dissertations that deal with various aspects of computer-based information technologies and their impact on organizations is provided. Additionally, a review of relevant articles from academic journals and trade periodicals about advanced information technologies and their impact on organizations is provided in summary form. A brief discussion of Leavitt's model of organizational change is presented here, as well as a summary of Leavitt and Whisler's speculation about the impact of information technology on medium-size and large business firms. Huber's theory of the effects of advanced information technologies is included as background for further detailed presentation in Chapter 4 and Chapter 6.

Doctoral Dissertations

A search of American doctoral dissertations reveals that relatively little research has been conducted regarding the impact of computer-based information technologies on organizations. The doctoral dissertations that deal with computer-based information technology can be categorized into one of three groups. The first group considers the organizational impacts due to computerization, whether the impact is on management,

personnel, or the internal working environment within the firm. The second group of dissertations deals with computerization for a specific technology class or application. More recent dissertations in the second group deal with specific computer applications in a specific organizational setting; for example, office automation (OA), personal computers (PCs), computer-aided design (CAD), computer-integrated manufacturing (CIM), or advanced manufacturing technology (AMT). The third group of dissertations addresses engineering educational and career issues and the problems brought about by information and technology changes in the engineering profession. There has been virtually no dissertation research integrating organizational models and empirical investigations.

A summary of relevant doctoral dissertations in chronological order indicates that both macro-level and micro-level research have been conducted with respect to computer impacts on organizations. As early as 1957, Stick addressed issues concerning computers and organizational structure. Knight (1963) studied the development and innovation of computers up to the early 1960s. Hofer (1969) investigated the effects of computer-based information technology on the organizational structure of two manufacturing firms. Van Voorhis (1971) researched the changes in traditional management functions caused by computerization. Hess (1974) investigated the computer influence on medium-size manufacturing organizations. Riehl (1977) researched the management practices in several firms concerning the development of business information systems. Wells (1978) traced the development of computers from an historical and technology change perspective. Burford (1979) studied developing trends in office technology and the changes to career paths brought about by these technology trends. Clowes (1979) studied the impact of computers on management and organizational issues. Kole (1979) investigated a behavioral approach to implementation of computer-based management information systems. Miller (1979) researched management information needs in small construction firms.

In the 1980s, a distinct change in the focus of doctoral dissertations is apparent. The doctoral research appears to focus on specific computer applications. Rehak (1981) investigated problems and issues relating to computer-aided engineering. Schultz (1983) studied microcomputer acquisition and usage strategies using Nolan's criteria for management information systems maturity. Edosomwan (1985) developed a methodology for assessing the impact of computer technology on productivity, production quality, job satisfaction, and psychological stress for the manufacture of printed circuit boards. Love (1985) researched design engineering performance and success in a high-technology environment. Spielman (1985) studied the impact of computer graphics on decision making activities. Beatty (1986) investigated the productivity of CAD operators at 25 Canadian sites in the manufacturing and resource sectors. Chismar (1986) investigated the economic impact of information systems technology on organizations. Floyd (1986) studied the effects on managers using electronic workstations. Fossum (1986) researched explanations for the slow progress for computer integration into U.S. manufacturing firms. Jurison (1986) conducted a one year longitudinal study of the impact of office automation on an aerospace engineering organization. Blanton (1987) performed a field study of the impact on quality caused by information technology support. Currie (1988) investigated engineering management's perceptions of the selection and implementation of computer-aided design (CAD). Gogan (1988) considered the effects of personnel usage and behavior caused by personal computers in organizations. Kotha (1988) researched business strategy, manufacturing structure, and computer-integrated manufacturing technology. Pavri (1988) conducted an empirical study of the factors contributing to microcomputer usage. Yoon (1988) investigated the relationship between advanced manufacturing technology and organizational structure.

More recently, Burton (1990) developed a model of the engineering design process. Kappelman (1990) studied the implementation of computer-based information systems. Lee (1990) conducted an empirical study of critical success factors relating to the effectiveness of the management of information systems in small businesses. Murotake (1990) examined the relationships between the use of computers in the engineering environment and project performance, and Robertson (1990) conducted a test of the information processing model with respect to CAD systems and communications in the engineering design environment.

In summary, an examination of relevant doctoral dissertations indicates that although some research has focused on organizations, there have not been any dissertations on the impact of advanced information technologies within the architecture and engineering design industry.

Journal Literature

What is conspicuously absent from the dissertation literature is theory-based research that deals specifically with the problems that architecture and engineering design organizations have had to contend with due to the rapid introduction of computer information systems and the continuation of legacy systems that were already in place. The published literature in journals tends to focus on descriptive and quantitative analyses of the effects of computers on engineering organizations. Case studies of specific companies are rare and instances of "success" relating to the use of advanced information technologies by specific firms are generally reported in the trade periodicals. On the other hand, instances of "failure" are virtually non-existent in the written literature.

The architecture and engineering design services industry has been profoundly affected by computerization, although belatedly compared to traditional accounting and financial data processing applications. The primary reason for the inherent delay of the computerization of architecture and engineering design activities is due to the complexity of the engineering process. Automating engineering activities has tended to concentrate upon the relatively mechanical aspects of design, like drafting and specifications. Daft and MacIntosh (1978, 1981) hypothesized that the information needs determine the most appropriate delivery medium. For example, complex, non routine tasks require rich information content; facial expressions and voice are the most appropriate means of information delivery for conveying complex and equivocal meanings. Therefore, computer-based information systems are more appropriate for simpler information requirements (Daft and Weick, 1984 and Daft and Lengel, 1986).

As early as the late 1950s, both Leavitt (1958) and Whisler (1958) predicted that the introduction of the computer would have a significant impact on the structure and processes of most corporations. Although there has been some formal research to investigate the nature

of this impact, the results of this research have been controversial and indeterminate. Leavitt's later research (1965) led him to conclude that for an organization to accomplish a given task effectively, four components were critical: task, technology, people, and organizational structure. Later, Culnan (1986) traced the origins of the information systems field to Leavitt and Whisler's article (1958) dealing with management issues in the 1980's. "Computer impacts" was identified as a specific sub field within the broad perspective of information systems.

Markus and Robey (1988) attribute some of the ambiguity in research conclusions concerning the value of information technology to inappropriate theoretical approaches to basic research. In some instances, empirical methods have been used to study organizational changes affected by information technology. However, they maintain that attempts to analyze information technology impacts empirically and then to infer or ascribe causal relationships are suspect.

The recent introduction of computer-based information technologies for engineering design is also a factor in the ambiguity and confusion that appears in the journal literature. "In the early 1970s there were only about 200 CAD/CAM workstations installed in the world. And almost all were in-house systems in large aerospace and automotive companies that could afford them. Virtually no one else had even heard of CAD/CAM." Twenty years later, approximately 1,000,000 CAD/CAM workstations were in active use (Krouse *et al.*, 1989).

In financial terms, in 1992, the worldwide market for engineering document management for hardware, software, and services was estimated as $602 million. By 1995, this market is expected to be $1.18 billion (Stover, July-August 1993). Market estimates for other, related engineering information software indicates that a tremendous financial investment has been made at the national level. The return on this information technology investment has been taken largely on faith by computer proponents, and especially by managers and engineers. As Zwass states: "It is paradoxical and, one should say, not a little

frustrating to both practitioners and theoreticians of management information systems that as information technology permeates more and more of the organization functions, the determination of its actual value to an organization still eludes measurement" (Zwass, 1990).

According to the premises of Rockart and Scott Morton (1984), the reasons for the lack of conclusiveness of the impact computers have had on an organization can be attributed to the nature of the three separate "eras" of computerization that have occurred. In the first era, paperwork processes of the firm were automated. Relatively few changes in an organization's structure resulted from merely automating the processing of accounting and paperwork functions. In the second era, emphasis was placed upon computerization of operational tasks in the organization. Manufacturing control systems and on-line order entry systems came into widespread use. Again, processing of data was automated, but little organizational impact was evident.

In the present, and third era, the emphasis is on providing information to top and middle management (Keen and Scott Morton, 1978) and on facilitating data analysis functions and communication of this analysis. This era can be labeled the 'information-communication' applications era, and changes brought about by computerization of these business functions does result in major changes to organizations (Rockart and Morton, 1984).

Rockart and Morton also believe that "there are two principal driving forces external to the firm that affect organizational strategies, personnel, structure, and technology: the external socioeconomic environment and technology." These two forces cause the organization to direct its internal elements, technology, strategy, management processes, people, and organizational structure, to meet these external pressures.

Due to the relatively recent introduction and wide-spread use of computers in engineering design, major changes have occurred in the manner in which engineering design services are performed. Numerous engineering firms have implemented various technologies, especially computer-aided design (CAD) systems, in order to improve quality, lessen cost, and increase productivity: imperatives facing all firms in a competitive environment. There is some documented evidence that the introduction and use of CAD systems have indeed resulted in improved quality of the products developed (Crombez, 1988); (DeMatthew, 1989); (Eade, 1989); (Velocci and Childs, 1990). Some firms have managed to reduce development costs of new product designs (Smith, 1982; Dutton, 1986; Fitzgerald, 1987; Krouse *et al.*, 1989). Other firms have experienced substantial reductions in the time required to develop new products and designs for their consumer markets, and thereby have improved their productivity (Fitzgerald, 1987; Bull, 1987; Frangini, 1990; Manji, 1989; Teresko, 1990).

Conversely, however, some surveys of managers indicate that not all firms have experienced positive results from the introduction of CAD systems. Some managers believe that CAD systems have not delivered expected benefits. This skepticism is only exacerbated by the additional information management burdens that have resulted from the incorporation of newer image-producing and storage technologies. Engineering documents management has become a separate job category in engineering departments, although the importance of this position does not yet seem to be widely recognized nor acknowledged (Wells, 1987).

Robertson and Allen (1992) conducted field interviews at ten companies utilizing CAD systems for mechanical engineering applications. First, they concluded that there are significant productivity benefits gained by using CAD systems. Second, CAD systems provide a common language or set of references that, in turn, leads to more effective communications about design related issues. Third, many engineering changes are enabled only by the use of CAD systems if the work is reorganized to exploit the features of the systems. Lastly, they conclude that CAD systems may initially require more investment in time since more issues may be raised earlier in the design cycle. CAD systems will not cause any major changes by themselves, but may enable changes that will lead to significant productivity increases.

Forslin *et al.* investigated the introduction of CAD in an engineering company (1989). They concluded that the introduction of CAD as a technology had fewer desirable effects on the work environment of the designers than expected. They felt that CAD technology will have little effect on a bureaucratic organization unless change, per se, is included as an explicit objective.

In a survey of U.S. manufacturers conducted by the National Electrical Manufacturers' Association (NEMA), all sizes of firms will be actively involved in installing CAD/CAM systems in their facilities (U.S. Department of Commerce, 1987). Smaller firms will have no prior experience with this technology and will, consequently, require additional planning, and even outside assistance, to install CAD/CAM systems.

In 1987, it was estimated that twenty-five percent of all companies in the United States would employ integrated CAD/CAM systems by 1990, compared with twenty percent in Japan and ten percent in the United Kingdom. Japan and the Western European countries are beginning to apply CAD/CAM technology on a widespread basis due to the decline in growth of some of their basic industries (U.S. Department of Commerce, 1987). Although the United States holds the lead in the rate of application of CAD/CAM systems, neither the United Kingdom nor Japan is more than five years behind in implementation. Therefore, as an international consideration, the effective utilization of CAD and related advanced information technologies has significance at the national level.

Due to the recent appearance of other forms of advanced information technologies, the research literature relating to these effects on engineering firms is extremely sketchy. Empirical research, even at a descriptive level, is not available. There are at least four reasons for this lack of information. The first reason is because of the predominant form of the articles of incorporation for architecture and engineering firms. Most A&E design firms are chartered as either partnerships or closely-held corporations and, therefore, are not required to release financial information external to the firm. Financial information for engineering firms is not available from governmental sources except as aggregate data. Therefore, engineering costs are embedded as research and manufacturing costs. The second reason is due to the recent development and use of advanced information technologies; for example, digital imaging, scanning, and other electronic documents management technologies that have been developed in the past decade. The third reason is because of the general reluctance by owners of the A&E design firms to reveal information relating to their business and technology strategy to their competitors. The fourth reason results from the legal and business requirement for the confidential treatment of client information, thereby limiting publicly available information. In short, all of these reasons combine to create a knowledge void in an important national industry.

In summary, in some instances, the introduction and implementation of advanced information technologies in engineering design firms have produced counterproductive effects. The lack of conclusiveness of the research on the utilization of these information technologies in engineering design has resulted in controversial and often inconsistent conclusions. Therefore, the need for research into the impact advanced information technologies have had on engineering design seems particularly appropriate considering that this industry segment is composed largely of highly paid and highly skilled professionals and whose services are used in the design and construction of virtually every physical structure built for society.

Leavitt's Organization Model

In a seminal article, Harold J. Leavitt (1965) presented a model of organizational change that included four interacting variables: task variables, structural variables, technological variables, and human variables. He suggested that further understanding of organizational change could be viewed in terms of three approaches: *structural* approaches, *technological* approaches, and *people* approaches. He further presented these variables and approaches in a four-factor graphic diagram shown in Figure 5 in Chapter 4.

Leavitt defined the four variables of his model. *Task* referred to industrial organizations' *raisons d'être:* the production of goods and services, which also included operationally meaningful subtasks that could exist in complex organizations. *Actors* referred primarily to people, but also included acts executed by people that did not necessarily remain exclusively in the human domain. *Technology* referred to problem-solving inventions, such as work-measurement techniques, computers, or drill presses. Leavitt included both machines and programs in this variable category. *Structure* referred to systems of communication, systems of authority, and systems of work flow (Leavitt, 1965, p. 1144).

Leavitt recognized that the four variables of his organizational model were highly interdependent and portrayed this with bi-directional arrowheads, in order to show that any change in one variable could produce compensatory (or retaliatory) change in others. He presented a brief discussion of the impacts caused by the introduction of new technological tools, computers, for example, which might cause changes in organizational structure, changes in actors or people, and changes in performance or task definition.

In summary, Leavitt's article was an early analysis of the impact of computerization on organizations, especially large organizations. Later researchers have credited Leavitt's article and later research as seminal research within the field of information technology.

Leavitt and Whisler's Predictions

In 1958, Harold J. Leavitt and Thomas L. Whisler presented their views of the influences that computers would have on management in the 1980s. They refer to the new, unnamed technology as *information technology*. They viewed this new technology as being comprised of three related parts. The first part included techniques for processing large amounts of information rapidly, epitomized by the high-speed computer. The second part centered around the application of statistical and mathematical methods for decision-making. Such techniques as mathematical programming and operations research were cited as examples. The third part of *information technology* consisted of the simulation of higher-order thinking through the application of computer programs.

Leavitt and Whisler's article also presented their predictions for the influences of *information technology* on management. Although highly descriptive, their forecasts are remarkable for their accurate, although imprecise, portrayal of the effects of computerization on organizations. More remarkable is their analysis of these effects on management and people within organizations and their suggestions for management to prepare for the changes that would occur due to the widespread adoption of information technology.

Leavitt and Whisler's research and publications about the effects of information technology on organizations provided the foundation for later researchers that studied organizations, people, and technology and the relationships among these.

Huber's Theory of Advanced Information Technologies

Organizations have been increasingly affected by the introduction and utilization of advanced information technologies into the work environment. Recognizing this, Huber (1990) proposed a theory of the effects of advanced information technologies on organizational design, intelligence, and decision making. The need for a theory that addresses these effects is predicated on the multiple changes that have occurred in the various forms of communication technologies. According to Huber, much of our knowledge about the factors affecting organizations, their processes, structures, and performance, was developed at a time whenever communication technologies were relatively static and unchanging. Therefore, theory that restates the structure of the organization in terms of more advanced technologies dealing with information is needed.

For example, in the past decade alone, electronic mail, computer conferencing, video-conferencing, and other forms of image transmission technologies have been introduced into corporate environments as computer-assisted communication technologies. Additionally, the capabilities and forms of these technologies are likely to change even more in the future. Other examples of computer-assisted communication technologies that are now in use in most large organizations include voice mail, facsimile transmissions, cellular telephones, and wireless networks. Examples of computer-assisted decision-making technologies now in common use are computer-aided design, management information systems, and internal and external information retrieval systems.

As other researchers have noted, " ... new media impacts may condition or falsify hypothesized relationships developed by past research" (Williams and Rice, 1983). Therefore, a sound theory supported by empirical evidence is needed since it is likely that additional organizational impacts will continue, along with an increasing amount of variation in the types of advanced information technologies used by organizations in the future.

Huber presents four motivations for proposing a theory of advanced information technologies. First, the need for reinvestigation and possible revision of organization theory might be indicated due to the relative recent introduction and use of communication technologies. Much of the research about the factors that affect organizational processes, structures, and performance was conducted at a time when the nature and mix of communication technologies were relatively fixed across organizations of the same general type.

A second motivation is that a theory could provide an explanation of the effects that advanced information technologies have on organizations. Although there have been many empirical findings concerning the effects of advanced information technologies on organizations, "there has been little synthesis, integration, and development of theoretical explanations," [and] "that it is time for theory development and theory-guided research" (Steinfeld and Fulk, p. 479).

A third motivation is that an integrating theory can assist organizational researchers, communication researchers, and information systems researchers to become more aware of the existence, content, and relevance of work performed by other researchers in other fields. Without this awareness, the synergistic opportunities and the efficiency of research efforts are lost.

The fourth motivation for a theory is for the practical application of principles that administrators of organizations can use as guidelines in predicting and planning for the organizational impacts caused by the use of advanced information technologies.

Huber recognizes that the theory he proposes is not based upon a large amount of directly applicable empirical research. The reasons for this are twofold. First, the components of organization theory that were utilized in developing the propositions of his theory were not validated under conditions in which communication and decision systems were computer-assisted. Therefore, these components may not necessarily be valid for organizations that are currently using a substantial amount of advanced information technology (Huber, p. 49).

The second reason for the lack of empirical support for his proposed theory is that many of the empirical studies that were used inductively in developing the propositions pertain to technology forms that might not be representative of the more sophisticated forms now in use or expected to be in use in the more distant future (Huber, p. 49).

These caveats aside, Huber recognizes that propositions about the organization-level effects of advanced information technologies must be considered cautiously. However, he feels that his propositions are supportable if relevant qualifications are applied seriously by users of the theory (Huber, p. 49).

Huber's theory and propositions are directly related to the research conducted for large architecture and engineering firms because of the nearly universal shift within the A&E design services industry from traditional engineering tools to various advanced information technologies. A list of traditional tools and instruments used to generate, reproduce, or transfer engineering information is provided in Appendix C. As a contrast, a list of some of the advanced information technologies currently in use at large A&E design firms for generating and distributing engineering information is provided in Appendix D. Huber's theory and related propositions provide a cohesive view of the organization from an advanced information technology standpoint. Huber's theory and propositions are used as part of the research model for conducting the field research and some of the subsequent research analysis of the research findings. Huber's theory in graphic form is provided in Appendix H. The propositions that he defines to support each concept have been added to the chart by the researcher.

Huber’s theory of the effects of advanced information technologies on organizational design, intelligence, and decision making includes a set of fourteen propositions that deal with various aspects of organizations from the perspective of advanced information technologies.

These propositions focus on the impacts of AIT on the organization from the perspective of the subunit level, the organizational level, the organizational memory and performance variables. Huber also presents these propositions as a grouping of dependent variables related to the organization. The subunit level, organizational level, and organizational memory variables are defined as dependent variables. The independent variable, performance, refers to the effectiveness of organization's ability to use information obtained through the use of advanced information technologies.

Huber summarizes the prior research in this area and concludes that synthesizing of the various theories, models, and hypotheses relating to computer-based information technology is needed. Huber cites Williams and Rice (1983) to justify the need for reassessment of what is known about advanced information technologies due to change in these technologies and he maintains that "new media impacts may condition or falsify hypothesized relationships developed by past research."

Appendices H, I, J, and K provide more detail of the basic components of Huber's theory. Huber's fourteen propositions relating to advanced information technologies and their relevance to the research findings are discussed more extensively in Chapter 6.

Chapter Summary

A review of published journals and articles indicates that there have been substantial changes in organizations due to the use of various forms of computer-based information technologies. Architecture and engineering firms have also adopted various forms of advanced information technologies, but there is little related published research for this industry. Chapter 3 presents the research approach or method used for conducting the dissertation research. It also summarizes the major aspects of the dissertation research model.

CHAPTER 3

RESEARCH METHOD

Chapter Objective

The objective of Chapter 3 is to present the research method used for the conduct of the field research. Background information is provided, tracing the development of the research model. A discussion of the Delphi technique, its strengths, its limitations, and its use in developing the research model is also presented. Chapter 4 presents the research model used as a framework for conducting the field research and for interpretation of the research findings.

Introduction

The research approach or method used for the field research consisted of the following major items:

1. development of a research model from a synthesis of organizational models proposed by Leavitt, Huber's theory of advanced information technologies, and the addition of a fifth component to the model of organizations proposed by the researcher,

2. development of a research questionnaire through the use of a panel of experts using the Delphi technique,

3. development of a set of competency indicators using the expert Delphi panel,

4. interviews of appropriate management, architects, engineers, and designers using the questionnaire developed through the Delphi process,

5. summary and analysis of the results of the interviews and field research using the framework of the research model.

The field research was conducted using site visits, interviews, and personal observation techniques for eliciting the information needed to develop descriptive summaries of each A&E design firm visited. The combination of these research methods provided the advantage of increased flexibility in exploring the underlying reasons for organizational impacts due to the utilization of advanced information technologies. Additionally, the personal interview method provided opportunities to probe and discuss issues not amenable to questionnaire and survey methods and to obtain immediate clarification of responses. Discussion of sensitive topics relating to the impacts on personnel was also possible and in a manner that could not have been accomplished by other research methods.

An analysis of responses to the research model questions posed to interviewees was conducted using the research model as the conceptual framework. Conclusions relating to the integration of advanced information technologies in A&E design firms were derived from assessment and analysis of interviewee responses in view of relevant literature.

Architecture & Engineering Design Firms

Field research was conducted for six architecture and engineering design firms with corporate or regional offices in the eastern United States. Since A&E design firms are in the services industry, it is was presumed that geographical location would not be a variable for purposes of this research. A brief synopsis for each of the A&E design firms is provided in Appendix B.

The architecture and engineering design firms that were visited for the field research were recommended by the members of the Delphi panel. The A&E design firms recommended by the expert Delphi panel are those that were considered as successful or competent in the acquisition and utilization of AIT. Five of the firms visited were recommended by one or more of the participants in the Delphi process. A visit to one of the six A&E design firms was secured through direct contact by the researcher.

Since acquisition of advanced information technologies requires substantial human and capital investment, a further restriction was that only A&E design services firms with annual billings in excess of $30 million were considered and contacted for field research. McGraw-Hill's *Engineering News-Record* was utilized as the basis for establishing annual billings and classification within the A&E design services industry. This annual industry report contains self-reported financial information and is not subject to audit or external confirmation. The report is one of the few sources of information available for researchers, however.

Firms that are considered to be primarily construction-oriented were not considered for the research. This restriction was applied in order to maintain additional homogeneity for the sample set. Architecture and engineering firms with a heavy emphasis on construction typically devote more resources to the construction activities and less emphasis to engineering design tasks. Therefore, their dependence on advanced information technologies is believed

to be much less than that exhibited by A&E design firms involved in project planning and design services.

Interview Method

Principal managers, engineers, and designers employed by the six A&E design firms were interviewed for obtaining the empirical data for each firm. The interview questions used were based upon the final research questions developed within the framework of the research model and were those developed with the participation of a panel of experts using the Delphi process. Background information on each firm visited was obtained through industry information services. Managers, engineers, and technicians within the architecture and engineering firms were used in order to obtain a vertical perspective of each firm's internal utilization of advanced information technologies. Due to personnel turnover, job changes, and the high rate of technology change and innovation, it was felt that a single individual would not be aware of all of the organizational changes and other events that occurred within the firm due to the introduction of computer applications. Additionally, a perspective of the firm's activities with respect to AIT at different management levels was obtained. Several individuals at each firm were interviewed in order to obtain an accurate assessment of the firm and the utilization of advanced information technologies. In all cases, at least one level of management was included in the interview process.

Delphi Background

A panel of experts was used in a Delphi process for developing the research questionnaire and the competency indicators. Discussion of the membership of the Delphi panel and the functions of the expert Delphi panel are presented in a following section.

The Delphi panel technique, developed by Norman Dalkey and Olaf Helmer of the Rand Corporation (1963), was used to develop a set of research questions, and also, a list of indicators for assessing the degree of competency for implementation and utilization of advanced information technologies for architecture and engineering design firms. Delphi is the name of a set of procedures for eliciting and refining the opinions of a group of experts or especially knowledgeable individuals (Dalkey, 1972). It can also be used for developing survey or research questionnaires that are used in forecasting the occurrence or application of technologies. The effectiveness of the Delphi technique for assessing technological impacts in a business setting has been substantiated by the empirical research of Saren and Brownlie (1983).

There are three recognized situations for technological forecasting where expert opinions will always be needed. The first occurs whenever no historical data are available on which to base decisions. In the instance of new technologies, historical data usually are not available since there has not been sufficient time to accumulate operating information or standards of performance. Expert opinion is, then, the only possible source of a forecast (Martino, 1983, p. 14). Use and implementation of new technologies that perform functions not previously attainable by older methods or technologies are an instance where the use of historical data for forecasting purposes is unacceptable due to the inability to compare "old" methods with "new" methods.

Second, the use of expert opinion is indicated whenever the impact of external factors is more important than the factors that governed the previous development of the technology.

These factors could include decisions of sponsors, or decisions of the opponents of the technology, or changes in public opinion (Martino, 1983).

The third situation that mandates the use of expert opinion is that in which ethical or moral considerations may dominate the economic and technical considerations usually accompanying technology development. These issues are typically subjective, and expert opinion may be the only possibility for obtaining a technology forecast (Martino, 1983).

Statistical studies have shown that normally three, and occasionally four, iterations of expert opinion "voting" are needed in order to reach response stability on anonymously submitted questionnaires. Although the expert panel responses will tend to indicate a consensus, the real, but often misunderstood, purpose of the Delphi technique is to support divergence and dissent. Analysis of differences of opinion can reveal causal relationships within a complex socio-technical environment (Martino, 1983). Hence, the requirement for anonymity, as opposed to face-to-face solicitations used in the nominal group technique or in open colloquia sessions, is a distinctive strength of the technique.

Panel Membership

Research on the Delphi process indicates that expert representation for the primary issues to be researched should be the criteria for the selection of panelists, not necessarily the breadth of each panel members' expertise (Martino, 1983). Martino reports that a panel size of 11 to 15 members is as valid as a much larger group. He reported that continuity of participation by panel members is also more important than the group size.

Industry consultants, publishers, engineering practitioners, and academic researchers were selected as the set from which to choose the panel membership. A list of the experts used in the Delphi process, their organizational affiliation, and position or title are provided in Appendix A.

Experts and representation on the Delphi panel for the following areas was obtained in order to address these aspects of architecture and engineering firms:

Architecture & Engineering design management
Computer-Aided Engineering technologies and practices
Engineering documents and information management

These areas cover the internal environment of the architecture and engineering firm and the advanced information technologies utilized in performing engineering design services.

The initial list of candidates for the Delphi expert panel was obtained from the researcher's personal knowledge of the quality and nature of their involvement in computer-aided engineering and information management issues. Other panel candidates were obtained from recommendations of the initial Delphi panel members. Ultimate selection of a prospective expert as a Delphi panel member was made by an assessment of the individual's achievements and recognition within his or her area of expertise. A notable record of publications and conference presentations was considered to be basic evidence of this expertise. Other criteria, such as length of experience in the industry, holding a position of

significance, and academic achievements, was used for final determination of the panel membership.

Administration of the Delphi Process

An initial set of research questions was developed and submitted to the panel of experts that participated in the Delphi process. The initial questions were those that the researcher has encountered in various engineering firms and frequently occur in the trade literature as anecdotal writings. These questions were submitted by mail to the expert Delphi panel as a conceptual research model that is presented as a graphic in Appendix E and discussed more extensively in Chapter 4. On the basis of critique of the initial set of questions and suggestions from the Delphi panel for additional questions, the initial set of research questions was then reworded and modified to investigate additional aspects of the conceptual research model, that is, the five components: structure/strategy, technology, task, personnel, and information. Three iterations of the Delphi process were conducted in order to assure that a comprehensive set of research questions were obtained and that there were no omissions or excessive redundancy among the questions. Divergence and different views from the Delphi panel were incorporated in the second and third iterations in order to ensure that important questions were not omitted on the basis of predominance of agreement. As Dalkey and Helmer maintain (1963), the Delphi technique is not to be utilized for just obtaining consensus among the panel of participants. Representation of divergent views or dissenting opinions is important also for the technique to result in a proper resolution or conclusion.

Counting the initial questionnaire, expert Delphi panel members received three mailings of the research questionnaire. The responses received were resubmitted two times to each of the participants with a request for responses to either the research question or comments on the responses of the other participants. Stability and closure was obtained after three iterations as evidenced by repetition and close similarity of suggestions. This is consistent with empirical research of the Delphi process which suggests that only rarely are four pollings of a panel required to reach closure of opinions on issues (Martino, 1983).

Providing an initial research model to the Delphi panel members typically reduces the number of pollings in the Delphi process to three. The final set of research questions obtained from three iterations of soliciting responses from the expert Delphi panel was edited, reorganized, and utilized for conducting the interviews at the six A&E design firms.

Since it was assumed that some panel members were professional acquaintances of other members, explanation of the need for anonymous responses and confidentiality was explained to the selected participants in an introductory letter covering the requirements and procedures of the Delphi process. Confidentiality of all responses from all panel participants was maintained throughout the research and is discussed in more detail in the following section.

The experts selected for the Delphi panel were instructed in the Delphi technique, its operation, the need for secrecy of responses, and the iterative process. Of critical importance was their awareness of the need for thoughtful, professional review of the issues, questions, and responses given, and their active role as developers of a set of competency indicators for implementation of advanced information technologies in A&E design firms.

Although all of the panel members have professional or academic interests in the dissertation research, the Delphi process eliminated the possibility of the views or opinions of a single individual from unduly influencing other panel members. By following the protocol for anonymity of responses, it is very unlikely that a single individual or perspective could be able to dominate the responses of the other participants.

An initial research model and set of research questions were provided to the expert Delphi panel by the researcher. A set of competency indicators for effective utilization of advanced information technologies was also submitted to the Delphi panel for their response and modification. The initial set of indicators was obtained from personal interviews with engineering practitioners (Bullock, 1994; Church, 1994), each with more than twenty years of experience in information technologies used in engineering and manufacturing environments.

Development of the competency indicators was obtained also from the expert Delphi panel and used during the collection of empirical data at the architecture and engineering firms investigated during the field research.

Confidentiality Requirements

The requirement for confidentiality of discussions relating to the research questionnaire and prospective architecture and engineering firms to be visited was submitted to the expert Delphi panel by written correspondence. During the field research, strict confidentiality of individual responses was maintained in order to obtain unbiased responses from prospective interviewees at the firms visited. Copies of the overall analysis and findings of the research, however, were offered to each architecture and engineering firm participating in the research study as an incentive for participation in the study. The identity of the firms visited, however, are disguised in all respects in the dissertation. References to any firm by name or specific geographic location has been avoided in order to preserve the confidentiality of the firms.

Functions of the Expert Delphi Panel

The expert Delphi panel served three primary functions for the dissertation research. First, the panel members reviewed and critiqued an extensive list of appropriate questions designed to explore the competency indicators with respect to implementation, integration, and utilization of advanced information systems.

Second, the expert Delphi panel aided in developing a set of factors or indicators that one would expect to find in A&E design firms that are competent in the utilization of advanced information technologies. The objective of this set of criteria is to provide a basis for developing exploratory questions that are appropriate for on-site, personal interviewing to be subsequently conducted by the researcher.

A third function of the expert panel was to assist the researcher in obtaining the names and locations of specific engineering design firms suitable for on-site visitation and in-depth interviewing and observation of the engineering operations at each firm visited. The Delphi panel members collectively provided an extensive network of personal contacts in the architecture and engineering services community for the researcher. Personal references by the Delphi participants added credibility to the researcher's objectives and assisted in gaining appropriate access to key personnel in specific architecture and engineering firms that are considered to be competent implementers and users of advanced information technologies.

Chapter Summary

Chapter 3 presented the research method or approach used for conducting the field research and discussed the following major elements:

1. Submission of the initial research model and research questions to the expert Delphi panel for review, modification, and suggested additional research questions.

2. Refinement of the research questions for conducting the field research developed by an expert Delphi panel.

3. Submission of an initial list of competency indicators to the expert Delphi panel for review, modification, and suggested additional indicators.

4. Identification by the panel of experts of approximately 6-10 architecture and engineering design firms identified as competent users of advanced information technologies.

5. Field research consisting of personal interviews of managers, architects, engineers, and designers of the firms visited in order to determine the degree to which each architecture and engineering design firm has implemented advanced information technologies, the impact of various advanced information technologies, and whether these technologies have been effective for conducting architecture and engineering design services.

Chapter 4 presents the research model that was used as the guide for collecting the empirical data during the field research. The evolution of various organizational models related to the dissertation research is presented. An overall summary of the research findings within the framework of the research model is presented in Chapter 5 and Chapter 6.

CHAPTER 4

RESEARCH MODEL

Chapter Objective

The objective of Chapter 4 is to present the development of the dissertation research model used as the basis for conducting the field research, the research analysis, and the competency assessment instrument. A conceptual model of an organization model was developed from an integration of Leavitt's model of the organization and Huber's theory of advanced information technologies, plus the additional concept of 'information' as a distinct component of organizations. Some of the earlier models of organizations are presented in order to show their relationship to the development of the conceptual model of an organization. Justification for the addition of information as a fifth component of organizations is presented.

Background for the Research Model

There have been numerous models proposed by other researchers concerning the various variables that affect the infrastructure of organizations. Tracing the development of some of these organizational models is useful for showing how researchers have contributed to our understanding of the relationships among various components of firms. Information is an inherent, although not often obvious, feature in all of these models. Only in the past decade, with the impact of personal computers and other forms of advanced information technologies, have researchers begun to identify information as an important and integral component of modern organizations. Information can be visualized as the communications conduit among the other components of organizational models. Therefore, an historical review of organizational models is useful for showing the development of the research model used in the dissertation research.

Woodward's Model

Joan Woodward's (1958) classic, seminal research established causal linkages between an organization's structure and the technology being used. Her studies showed that technology does have strong influences upon the structure of an organization. Later research by Thompson (1967) confirmed some of the earlier findings of Woodward. A simple diagrammatic view of Woodward's research concept is presented as Figure 1.

Woodward's Model (1958)

Figure 1.

The arrow in the diagram indicates, conceptually, that technology, in the general sense, has an influence on the organizational structure of the firm. Woodward's research was also important because it showed that organizational research could reveal some of the hidden elements of organizations.

Chandler's Model

Another of the earlier organizational models was proposed by Alfred Chandler (1962), who maintained that an organization's structure evolves as a logical consequence of the organizational strategy being utilized. A diagrammatic view of Chandler's research concept is presented as Figure 2.

Chandler's Model (1962)

Figure 2.

Chandler studied various manufacturing firms and concluded that a firm's organizational structure is determined, at least in part, by the firm's strategy or mission.

<u>Emery and Trist's Model</u>

Emery and Trist (1965) researched the relationship between employees and the technology being utilized for coal mining. A diagrammatic view of Emery and Trist's research model is presented as Figure 3. They investigated the change in working relationships among coal miners as a result of a technological innovation; namely, the changes in the workers' environment that occurred whenever mining was changed from a group-oriented set of activities to an isolated environment produced by using machinery and heavy equipment to extract coal.

<u>Emery & Trist's Model (1965)</u>

Figure 3.

Emery and Trist's research is important because it shows that there is a change in the work environment due to a change in technology, and that this has an impact on the working relationships among people in that environment (Emery and Trist, 1965).

Hofer's Model

Hofer (1969) conducted dissertation research relating to information on business strategy for a manufacturing organization. A diagrammatic view of Hofer's research concept is presented as Figure 4.

Hofer's Model (1969)

INFORMATION → STRATEGY

Figure 4.

Hofer's research investigated the development and consequences of an organization's strategy in response to receiving or sensing information external to the firm.

Leavitt's Model

Some of the earliest research dealing with a more comprehensive view of the organization was conducted by Harold J. Leavitt and Thomas L. Whisler (1958). Leavitt and later associates of his investigated the multiple linkages that exist among major components of an organization. Later, Leavitt (1965) developed a four-factor model consisting of structure,

task, technology, and people. His model drew heavily upon the works of Argyris (1957), Chapple and Sayles (1961), and other researchers in the field of social psychology. As can be seen in Figure 5, Leavitt's model encompasses all of the components of an organization described by other researchers, except 'information' as a distinct and separate concept or entity.

The significance of computers and information as a major impact on organizations, however, was not apparent during the early 1950s since computers were only beginning to be commercially produced and used in business applications. Leavitt and Whisler (1958) are credited as the first researchers to observe and predict some of the effects of this impact of computers on organizations.

Leavitt's Model (1965)

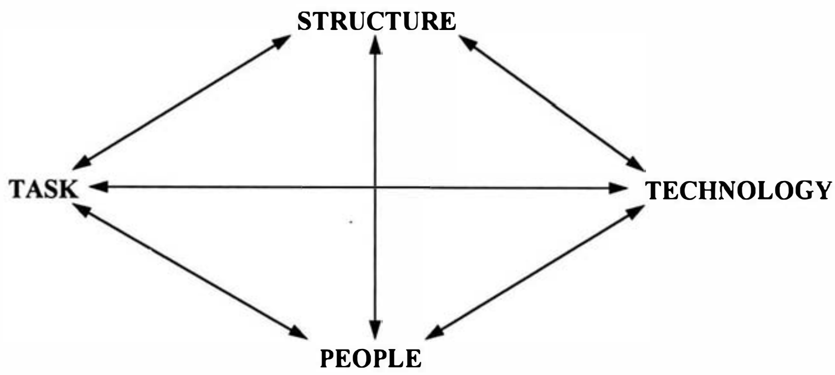

Figure 5.

Leavitt's model is noteworthy for portraying that the organization is composed of multiple factors or components and that the relationships among these components are bi-directional. Therefore, causality is often indeterminate since a change in one component may result in a change in another component, which, in turn, leads to a further change in the original independent, causal variable. As a model, however, the conceptual diagram is useful for showing these interrelationships in graphic form.

Daft and Lengel's Model

More recently, Daft and Lengel (1986) researched more subtle aspects of information and its purpose within an organization. A simple, diagrammatic view of Daft and Lengel's organizational model is presented as Figure 6.

Daft & Lengel's Model (1986)

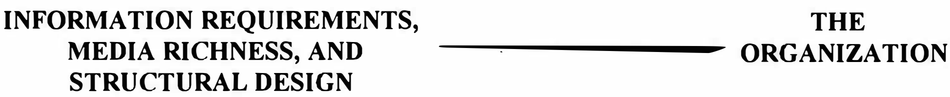

Figure 6.

Their research considered the forces of uncertainty and equivocality and their influence on information processing in organizations as an answer to the question, "Why do organizations process information?" Figure 7 presents a summary model from Daft and Lengel (1986), which was adapted from Tushman and Nadler's model (1978), to show their conceptual view of the organization's effectiveness in terms of information processing.

Daft and Lengel's Information Processing Model (1986)

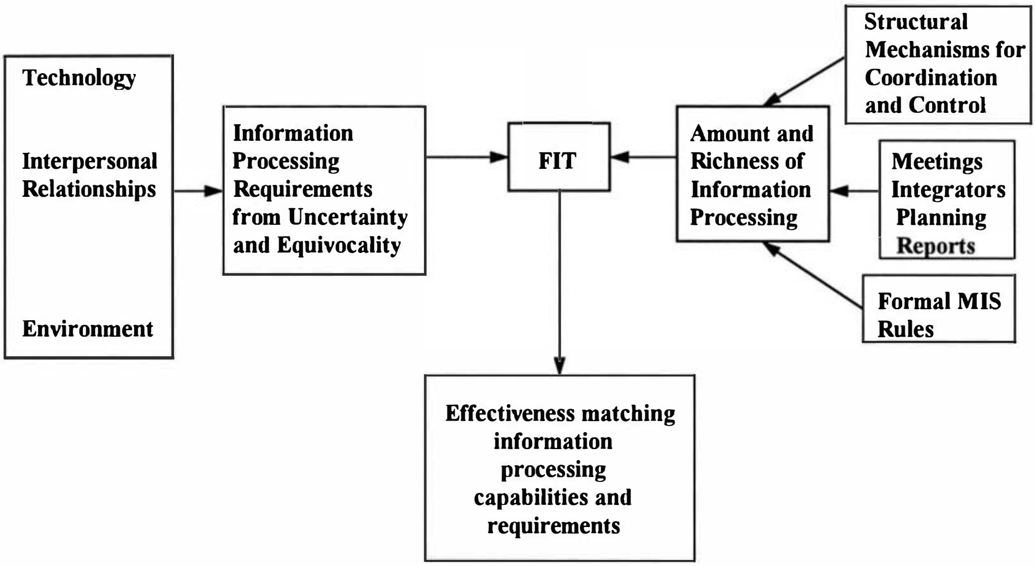

Figure 7.

As seen from Figure 7, Daft and Lengel believe that an organization develops effectiveness through a matching of information processing requirements for reducing uncertainty and equivocality with internal structural mechanisms for coordination and control. The information processing requirements can be met both by the use of traditional forms of communications as well as by the use of various information processing technologies.

Huber's Model

Huber (1990) proposed a theory that describes the effects of advanced information technologies on organizations in terms of organizational design, intelligence, and decision-making. A diagrammatic view of Huber's research model is presented on the following page in Figure 8. In brief, Huber's model focuses on the improvement in the effectiveness of intelligence development and decision making. The availability of advanced information technologies leads to their adoption and use in organizations. Commensurate with this use of AIT, subsequent increases in information availability then leads to changes in organization design. And ultimately, the increased information availability and changes in organization design leads to improvements in the organization's intelligence development and decision making.

Huber's fourteen propositions are discussed more extensively in Chapter 6. Huber's theory formed the theoretical basis for the development of the dissertation research model used and, combined with Leavitt's model of the organization, provided a structure for the development of the research questionnaire used in conducting the field research.

Huber's Model (1990)

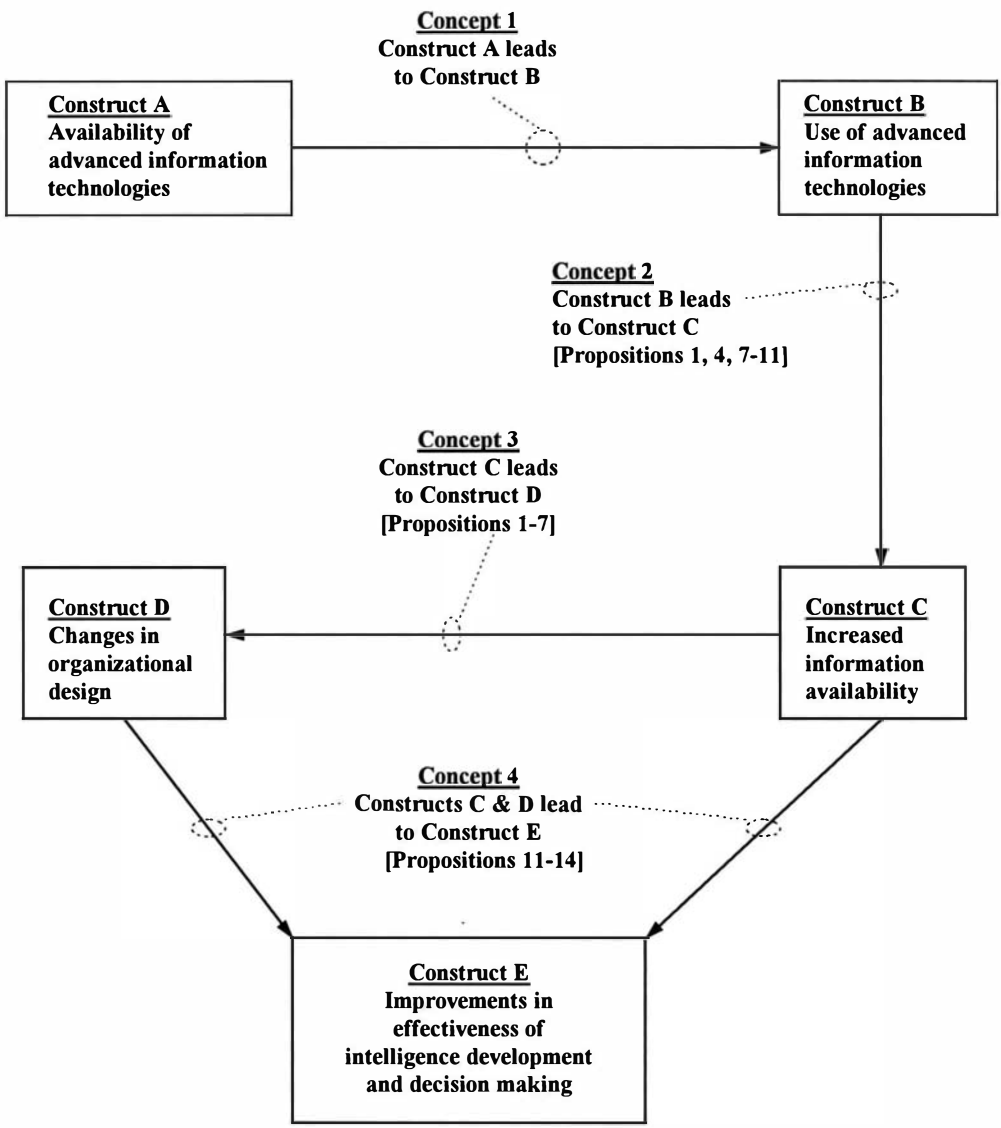

Figure 8.

Dissertation Research Model

The conceptual model of the organization used in the dissertation was developed by synthesizing of Leavitt's organization model (1965), Huber's theory of advanced information technologies (1990), and the addition of 'information' as a distinct component of organizations. A mapping of each of Huber's propositions into the appropriate category of Leavitt's organization model and the 'information' categories shows the congruence of Huber's propositions. However, Huber's theory focuses on the effects of advanced information technologies and information as distinct impacts on organizations. Considering the quantity of literature justifying the incorporation of 'information' as another organizational component, the conceptual model of the organization included information as a fifth factor.

Viewing the organization in terms of five components provides a broader perspective of organizations that use advanced information technologies. The 'technology' component is shown as a separate component from the 'information' component in order to make the distinction between the use of technology for purposes other than that to process information. The definition of the 'technology' component in the research model is that according to Huber's definition of AIT; that is, those technologies used specifically for transmitting, manipulating, analyzing, or exploiting information, as opposed to those technologies used for computer-assisted production or for transaction-enabling. A diagram of the conceptual model of the organization used for the dissertation research is shown below in Figure 9 and is also reproduced in Appendix E.

The research questionnaire and the competency assessment instrument were developed using an expert panel and the Delphi process and are discussed later in following sections in this chapter.

Conceptual Model of the Organization

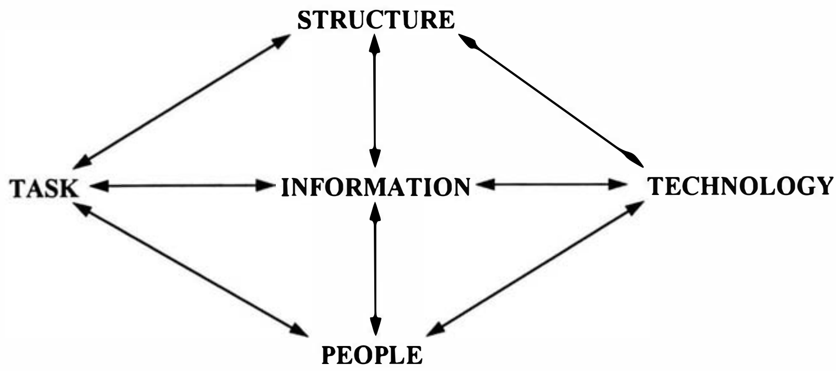

Figure 9.

The complete dissertation research model consisted of the following: a conceptual model of an organization (Figure 9); a mapping of Leavitt's model of the organization with Huber's theory and 'information' as a distinct addition for the complete research model (Figure 11); a series of research questions divided into the basic groups of the conceptual model used to assess the impact of advanced information technologies (Appendix G); an interpretation of the research findings against the fourteen propositions of Huber's theory of advanced information technologies (Chapter 6); and, a set of qualitative competency indicators (Appendix L) which was utilized to rank the A&E design firms. The qualitative competency indicators are further discussed in detail in Chapter 5.

An overall diagram of the complete dissertation research model in Figure 10 shows the overall process used in conducting the research and in developing the competency assessment instrument. Arrows between each of the dissertation topics shows the basic sequence that was followed for conducting the dissertation. The relevant chapter or appendix is also provided here as a guide for the reader.

Dissertation Research Model

Dissertation Topics	Presented in:
Evidences for Changes in A&E Design Firms from Literature and Anecdotal Testimonials	Chapter 2.
Examination of Theories Related to Effects of Advanced Information Technologies on Organizations	Chapter 4.
Research Model: Mapping of Leavitt's Model, Huber's Propositions of Advanced Information Technologies, and 'Information'	Chapter 4; Appendix F.
Expert Delphi Panel: Refinement of Research Questions	Chapter 3.
Field Research:	
1. Research Questionnaire	Appendix G.
2. Huber's Propositions	Appendix H.
Interpretation of Field Research:	
1. Research Questionnaire	Chapter 5.
2. Huber's Propositions	Chapter 6.
Competency Assessment Instrument	Chapter 5.
Research Conclusions	Chapter 7.

Figure 10.

Viewing organizations in terms of Leavitt's classic model with its components of structure, people, task, and technology, and the additional organizational component of 'information' provides the framework for investigating what the impact of AIT has been on architecture and engineering design firms. Although much of the literature treats information as an integral part of the organization's technology, the dissertation research model makes the distinction between technology per se and the information that is produced and utilized within the organization, regardless of the means of production or dissemination. Information is the means by which the organization integrates and utilizes the other four components in order to accomplish the organization's mission or objective. Therefore, the researcher believes that 'information' should be treated as a distinct organizational entity.

As discussed in Chapter 3, the questions for the field research questionnaire were developed through the administration of a Delphi process using experts in various facets of advanced information technologies and their use in A&E design firms. An evaluation list of competency indicators was also developed through the participation of the Delphi panel of experts that provides a means of qualitatively assessing the competency of A&E design firms in their use of advanced information technologies.

The conceptual diagram or view of an organization as portrayed by Figure 9 shows the possible relationships that can exist among the various major components: structure, technology, people, task, and information. The arrows indicate that there are influences and relationships among the major components and do not imply causality. Although some organization research indicates that there are causal relationships between the major components of organizations, the dissertation research conducted did not seek to show these relationships except as impacts to the overall organization or other components of the organization presented in the research model of the organization.

As a part of the research model, empirical evidence collected during the field research was interpreted against the fourteen propositions of Huber's theory of advanced information technologies. In order to develop an effective research model, and yet maintain the overall richness of Huber's theory, a mapping of his fourteen propositions within the organizational model first proposed by Leavitt was developed. This provided the simplicity desired, yet maintained all of the propositions in their original form. Although specific mapping of Huber's propositions into one of Leavitt's four components is somewhat arbitrary, the most appropriate category was selected by the researcher. An overall diagram of the entire dissertation research model showing Leavitt's conceptual model of the organization, the addition of 'information' as a fifth component of the organization, and a mapping of Huber's propositions into the entire model is presented in Figure 11 on the following page and also in Appendix F. As can be seen, Huber's propositions can be mapped into one of the five components of the conceptual model of an organization. Incorporating 'information' with Leavitt's model as a distinct component of the organization provides a basic structure for the conceptual model. This model also treats 'information' as a distinctly separate, but unifying component as implied by the positioning of 'information' in the center of the other organizational components as shown in Figure 9. Huber's propositions, as a corresponding part of the research process, provided a basis for obtaining additional evidence that helps to explain how organizations are impacted by the use of advanced information technologies.

In summary, then, a broader view of the organization than that suggested by Leavitt and other researchers was utilized for developing the research questions used in conducting the field research. Further discussion of the development of the research questionnaire and its use are presented in the next section.

Mapping of Leavitt's Organization Model, Huber's Propositions of Advanced Information Technologies, and 'Information'

	CONCEPTUAL MODEL OF AN ORGANIZATION				
	LEAVITT'S ORGANIZATION MODEL				
HUBER'S PROPOSITIONS	STRUCTURE	TECHNOLOGY	PEOPLE	TASK	INFORMATION
1			X		
2			X		
3				X	
4				X	
5	X				
6	X				
7	X				
8		X			
9		X			
10					X
11					X
12					X
13					X
14					X

Figure 11.

Development of the Research Questionnaire

Although Huber presents a number of propositions concerning the impact of advanced information technologies on organizational design, intelligence, and decision-making, these are only a few of the issues that exist in organizations. The dissertation research presents a broader view of the organization than that suggested by Huber's model.

An initial set of research questions was developed based upon the researcher's knowledge of information technologies in the architecture and engineering design disciplines. Input from two other practitioners (Bullock, 1994; Church, 1994) was also utilized to supplement the knowledge base of the researcher. Next, experts in various areas of advanced information technologies and in the practice of architecture and engineering design were contacted individually for participation in a Delphi process to develop additional research questions. The initial research questions were then submitted to each expert serving on the Delphi panel in order to obtain responses from each of the panelists. Utilizing the Delphi process, presented in Chapter 3, served to provide additional validation that the proper questions were obtained prior to the field research. Additionally, proper and careful wording of the research questions was obtained from using the expert panel through the iterative process of the Delphi technique.

As part of the initial questions submitted to the Delphi panel, the conceptual view of the organization proposed by the researcher was also presented in order to provide an overall common perspective for all the experts participating in the research. The questionnaire utilized a mapping of Leavitt's and Huber's models to provide a framework for developing research questions to be examined during the conduct of the field research. Leavitt's model provided a macro-view of the organization, while Huber's theory of the effects of advanced information technologies provided a basis for developing specific research questions to be used during the field research.

It should be noted that Huber's propositions were not utilized as the primary interview questions for interviews of managers, architects, designers, and engineers during the field research. This was done in order to avoid the likelihood of biasing the interviewees and thereby obtaining only positive or negative responses to questions that embodied Huber's propositions. A separate set of research questions, that is, those developed through the iterations of the Delphi process, was used for conducting the interviews of managers, architects, designers, and engineers at the six A&E design firms researched. Huber's propositions were, however, used as part of the overall research by examining the responses from the interviewees, supplementary discussions, and the personal observations by the researcher. In cases where the responses from the interviews did not provide empirical evidence to support or refute Huber's propositions, the researcher presented additional research questions to the interviewees by changing Huber's propositions to question form. Chapter 6 presents each of Huber's propositions in question form as used during the conduct of the field research and a brief presentation of empirical evidence obtained to support or refute each proposition.

The research findings obtained from the field research, therefore, are presented in two chapters in order to maintain the separation between the research findings obtained through the expert Delphi panel-developed research questionnaire and those research findings that relate to Huber's propositions obtained through supplemental interview questions and discussions at the six A&E design firms. The research questionnaire and Huber's propositions comprise separate categories of questions, but there is, however, overlap in the content and areas covered. In the case of the question form of Huber's propositions, for example, the objective was to obtain empirical evidence during the field research to either support or refute each of the fourteen propositions. Huber's theory focuses on the improvement of organizational effectiveness in terms of organizational intelligence and decision making brought about by the increase in information availability from the use of advanced information technologies.

Similarly, the dissertation research questionnaire sought to obtain answers to questions of significance to practitioners and managers involved in utilizing and applying advanced information technologies. The dissertation research model, then, incorporated two approaches using questionnaires for obtaining empirical data in order to obtain evidence to 'test' Huber's theory of advanced information technologies and to use for a competency assessment of the six architecture and engineering design firms researched.

Chapter 5 presents the research findings and responses to the research questionnaire developed by the researcher and refined through the use of the expert Delphi panel. Chapter 6 presents the research findings in terms of Huber's propositions. The dissertation research model was also used to develop a set of competency indicators for providing a qualitative assessment instrument that can be used by practitioners and researchers in the A&E design services industry.

Chapter Summary

Chapter 4 presented the basic conceptual view of the research model as an integration of organization models developed by Leavitt and Huber and the research questionnaire developed and refined through the Delphi process. Research models that incorporate information or information-related attributes that have been developed by various researchers were also presented in order to show their relevance to the conceptual model of the organization used in the dissertation research. The conceptual organizational model used in conducting the field research was presented, and Huber's theory of advanced information technologies and supporting propositions were discussed in the context of the field research. Chapter 5 presents the research questions that were used in conducting the field research and also the research findings for the six A&E design firms. The competency assessment instrument and its use in ranking the six A&E design firms are also presented in Chapter 5.

CHAPTER 5

RESEARCH FINDINGS

Chapter Objective

In this chapter, a synopsis of the empirical data is presented for the six architecture and engineering firms visited during the conduct of the field research. Responses to the research questionnaire, within the framework of the research model, are provided in summary form. A brief overview of each A&E design firm researched is provided in Appendix B.

Background: Architecture and Engineering Design Industry

The A&E design industry can be characterized as a diverse, complex, and competitive environment. The industry has traditionally employed highly skilled and educated technical personnel. In recent years, the external environment has become more competitive and turbulent due largely to a worldwide decline in new construction projects. Additionally, new local and national regulations dealing with hazardous wastes and safety requirements have introduced additional complexity and considerations for engineering designers of private and public projects.

Similar to law firms and professional corporations, engineering firms are usually incorporated as partnerships or private, closely-held corporations. They are usually named after the founding owners or partners. In many instances, access to financial data is limited to the owners or partners. In other cases, A&E design firms are large public corporations and are managed by professional engineers with ultimate ownership controlled by the shareholders.

Specialization in specific engineering disciplines for a specific industry or related industries is the usual organization form and industry classification. For example, an engineering firm may specialize in civil engineering and provide services for commercial construction. Another civil engineering firm may focus its services for the transportation market. Even in this area, further specialization is possible; for example, civil engineering for construction of airports, or civil engineering designs for the construction of highways. The periodical *Engineering News-Record* publishes an annual financial ranking of the top 500 U.S. design firms in the ENR Directory of Design Firms. The general categories used for classifying engineering design firms are: general building, manufacturing, power, water supply, sewer/waste, industrial/petroleum, transportation, hazardous waste, and other. A review of rankings indicates that changes in a given firm's relative position occur frequently, particularly for the smaller engineering design firms. This indicates the highly competitive nature of engineering design services, since successfully bidding on one or two major projects can result in major change and improvement in a firm's ordinal ranking. A “feast or famine” situation exists in the industry, and the industry, as a whole, is dependent upon the national and international demand for new construction or upgrade of existing facilities. Conversely, an A&E design firm's ordinal ranking can decrease drastically if it is unsuccessful in proposal bidding. Since engineering services are a commodity offering, selection and awarding of projects by clients is largely on a price basis, although other factors affect the ultimate selection of a specific design firm.

In recent years, an increasing amount of revenue for the larger A&E design firms has been obtained from international work. Among the top tier of twelve engineering design firms, with an aggregate billings of $500 million or more in 1993, the percentage earning attributed to international work ranges from a low of seven percent to a high of 94 percent, with an average of 35.8 percent. The percentage of international work among these firms is also significant whenever compared with that for the 1993 average billing percentage for the second tier design firms ($499.99 million to $200 million). This group consists of 23 design firms, averaging 13.1 percent billings for international work. The third tier of the top 500 design firms (billings totaling $199.99 million to $100 million) consists of 36 firms with an average of 11.4 percent of 1993 billings attributed to international work. In summary, international work accounts for a large portion of revenue for the larger A&E design firms. One of the reasons for this may be due to the economies of scale necessary to perform international engineering work, particularly if contractor-constructor services are offered. In this situation, the design firm would have substantial investments in heavy equipment and materiel in order to construct large facilities in foreign countries.

The larger firms typically provide contracting services in addition to engineering design. In brief, the design firm acts as the engineer for an international client and then, after design, as the contractor for the construction of the proposed facility, whether it be a pulpwood mill, a manufacturing facility, or a petrochemical processing unit. Variations on the engineer-contractor approach are common. An engineering firm, for example, might provide only the engineering design and documentation for a construction firm to build. Partnering for a joint sponsorship of a very large project is also another arrangement that provides additional flexibility and increased probability for successful completion of a large project. Engineering design firms can also supplement their engineering services by developing partnerships with other firms having specific engineering strengths in areas outside their expertise or capability.

In summary, architecture and engineering firms operate in a variety of industry segments. The engineering disciplines employed at each A&E design firm also vary according to the needs of their clients and the specialties served. The advanced information technologies used, however, tend to be the same or very similar. For example, all of the firms researched utilize the same CAD platform for their engineering design work. On the other hand, the document management practices and advanced information technologies employed were more varied, but tended to follow the engineering documentation cycle of: design concept, drafting, reviews, revisions, approval, release, and archive.

Introduction to Research Questions

The research questionnaire, based upon the research model derived from Leavitt's model and Huber's theory, and further developed through the Delphi technique, was used for conducting the various interviews at each A&E design firm. A synopsis of the empirical data collected during the research interviews is provided rather than an extensive itemization of all responses from all interviews. Similarity of responses are summarized as single statements regarding the impact of advanced information technologies. In the instance of divergent responses to a question, identification of the specific firm is provided to indicate the differences that were found to exist among the A&E design firms that participated in this research.

Organizational Strategy/Structure: Questions and Findings

The questions in this section were presented to the management of the six A&E design firms through an interview-discussion process. In most of the six firms, two or three management levels were interviewed. In the case of Firm B, however, there was only one manager, and therefore a single management level, that provided responses for questions in Section A. For the other firms, the range of management interviewed was from operations manager to that of senior vice president. There was some disparity in the responses as the levels of management increased. That is, in those firms where three levels of management were interviewed, the responses to the same question tended to have more variation. Although one could infer that the differences in perspective could be attributed to management visibility, the researcher believes that the disparity was more often attributable to the fact that at higher levels of management, there appeared to be less understanding of the issues related to advanced information technologies.

1. What have been the objectives of leading A&E design firms in acquiring and implementing advanced information technologies?

For most of the A&E design firms researched, the primary stated objective for the acquisition and implementation of advanced information technologies has been to deliver value to their clients. At Firm A, the objective of acquiring and utilizing AIT is to accomplish an engineering project in less time, at higher quality, and at lower cost to the client. At Firm B, the objective of acquiring and utilizing AIT is to reduce costs to the client. At Firm C, the objective of acquiring and utilizing AIT is to deliver higher quality to the client. At Firm D, the objective of acquiring and utilizing AIT is to improve productivity such that a better design is delivered to the client. At Firm E, the objective of acquiring and utilizing AIT is stated in terms of adding value to the client's project. In the instance of Firm E, an objective of "being in the game" was also stated as the reason for investing in various forms of AIT. At Firm F, the objective of acquiring AIT is to deliver a quality design to their customers at lower cost. Also, part of Firm F's business strategy includes becoming a leading competitor in their specific industry segment through the effective use of AIT.

Although some management responses were non-specific, it appears that the implicit intent of the objective in acquiring and utilizing advanced information technologies is to provide an advantage in terms of delivering increased value to the customer whether that value be reduced costs, shorter delivery times, better quality, or some combination of these.

2. **Do advanced information technologies favorably impact the "success" or "competency" of A&E design firms?**

For all six A&E design firms researched, the responses provided by management indicated that the use of AIT has favorably affected their "success" or "competency." Management at all six firms at all levels believe that advanced information technologies has made positive contributions to their firm. Various definitions of "success" were provided including increased productivity, improved quality, or reduced time to deliver a project. In not all cases, however, were managers at the six firms able to substantiate specifically how the use of AIT has actually contributed to their "success" or "competency." At Firm A, Firm C, Firm D, and Firm E, management reported that their use and commitment to various forms of AIT has resulted in their gaining engineering project work that would have otherwise been awarded to their competitors. At Firm B, management felt that AIT has permitted them to provide more opportunities for the firm in terms of new types of architectural design work. At Firm F, management was somewhat divided in terms of consensus about what constitutes "success" or "competency," but generally felt that the use of AIT had been a positive one for their firm.

3. **To what degree does the use of advanced information technology impact the achievement of productivity and quality objectives?**

The achievement of productivity objectives at the six A&E design firms is virtually non-quantifiable. There have been some attempts to define and measure productivity in engineering terms, but for the most part the difficulty of defining a reasonable measure and then incurring the continuing costs of monitoring the measures have resulted in the reliance on anecdotal evidence. Reduction in project delivery times is the most-often stated measurement for improved productivity. Reduced cost appeared to be a secondary measure or indication that the use of AIT have been worthwhile.

Quality imperatives, although much more difficult to define and measure, have been indicated by customer testimonials relating to their perception of improvement in the quality of documentation delivered as part of the project. Computer-aided design is the most obvious instance of improved quality in information deliverables. Data produced by other forms of AIT, such as electronic conferencing, has also contributed to the customer's perceptions of improved quality.

4. Is there a minimum set of factors that must be present for A&E design firms to be effective in the use of advanced information technologies? What are these factors?

At all firms, infrastructure was consistently cited as a prerequisite for the effective use of AIT, although there were also a variety of responses from managers at all firms. Firm A's technology manager cited the firm's culture and environment as a critical factor for AIT. Attitudes and value systems were also believed to be components of the firm's culture. Managers of technology at Firm B and Firm F felt that the existence of champions or sponsors for AIT is a critical factor. Firm B's manager cited upper management funding support as being critical. Firm C's management stated that attaining 'critical mass' in AIT is a critical factor, meaning that unless a firm can invest at a sufficient level, then the use of AIT will not be effective. A director at Firm D cited the need for engineering firms to redefine 'core competencies' before investing in AIT was a critical factor in their effective use. A corporate manager of computer integrated engineering at Firm E felt strongly that management commitment to appropriate user training was a vital factor for achieving effectiveness in the use of AIT. Firm F's management felt also that financial ability to acquire AIT at a sufficient level is an important factor. A senior manager and partner at Firm F also stated that critical factors are: (1) a demonstrated backlog of engineering work that could support the investment in AIT, (2) client demand for the use of AIT, and (3) a responsiveness to the opportunity for investing in AIT.

At Firm A, personnel attitudes and value systems were cited as factors in the effective use of AIT. The ability to change as new technologies are introduced and the company's environment were also believed to be important factors. At Firm B, critical factors cited were the presence of a champion within the organization and the desire among the firm's management to utilize AIT, including funding and approval. Firm C's information technology management cited as critical factors: infrastructure, presence and support of champions, and skilled personnel with effective training. Responses at Firm D and Firm E were essentially the same as those at Firm C. Firm F cited as critical factors: a demonstrated backlog of work that can support investments in AIT, client demands for use of AIT, and the ability to respond to the opportunity by the organization.

Other factors cited by management at the six A&E design firms included: (1) a properly trained and staffed support group; (2) management commitment to a long-range program of AIT investment; (3) a network system to provide interconnects among various user groups; and (4) sufficient financial funding to support the acquisition of AIT.

5. What are the indications or evidence for "successful" implementation of advanced information technologies?

Firm A cited indications such as reduction in the number, cost, and magnitude of field errors, engineering reworks, and redesigns. Firm B is utilizing AIT to transfer information on a global basis to provide innovative and distinctive architectural designs. By using the data transmission protocol of Multipurpose Internet Mail Extensions (MIME), Firm B has been able to receive offshore engineering designs, conduct design reviews at the corporate headquarters, and then transmit the final architectural designs to another country in a matter of hours compared to days and weeks before their implementation of AIT. Firm C's management reported that a standardized infrastructure resulted from the successful implementation of AIT that includes a standardized hardware and software platform and thereby leading to a more stable operation. Firm D's management believed that "a vibrant sense of urgency with respect to integration and implementation efforts" indicates a successful implementation of AIT; that is, if a firm is successful in the implementation of AIT, then the firm will be evidencing that by placing urgency on the activities and tasks associated with the use of AIT. A technology manager at Firm E felt that evidence of "successful" implementation would be represented by adoption, use, and dependence on AIT by a design firm's president or senior operating manager to accomplish relevant activities. An overall evidence of "successful" implementation would then be apparent by observing how the personnel of the firm are utilizing AIT to accomplish engineering design. Another manager felt that engineering documents integration with CAD technology would be strong evidence for "successful" implementation of AIT. Firm F's management felt with adequate financial leverage as a prerequisite, the availability of AIT permitted the firm to exploit the opportunity to utilize AIT. This, in turn, creates a perception that the use of AIT is an effective investment for the firm.

6. What are the indications or evidence for "successful" utilization of advanced information technologies?

Management at Firm A felt that the appearance of technology teams is an indicator of successful utilization of AIT. Firm B's manager of technology reported the use of more advanced forms of AIT, such as virtual reality software, would be evidence that indicated AIT's successful utilization at an A&E design firm. Firm C felt that responses from the firm's clients indicated their successful implementation of AIT. Additionally, the responses from the engineering users in terms of willing acceptance and use of AIT indicated successful implementation at Firm C. Firm E's corporate manager of technology stated that an overall assessment of what the firm's personnel are doing with AIT represents whether or not its implementation has been successful. In other words, if engineers and designers are using the acquired technology, then the implementation has been successful. Management at Firm F provided a distinctly different response from management at the other A&E design firms. At Firm F, management felt that the "successful" utilization would be indicated by using AIT as project management tools rather than as project accounting tools. For example, AIT have generally been used to automate the accomplishment of engineering design tasks, not project management of the design tasks themselves. A "successful" utilization of AIT would embrace their use as engineering enhancement technologies and include project management functions as an integral part of the technology implementation. Project schedules, for example, would be derived from a compilation of all the relevant engineering tasks. In the past, the project schedule was performed as a separate item, not as part of the engineering design process.

7. Are there identifiable similarities or differences among leading A&E design firms in terms of organizational strategy with respect to advanced information technologies?

At Firm A, Firm C, Firm D, Firm E, and Firm F, organizational strategy relevant to AIT focused on delivering value to the customer, whether that value be reduced costs, reduced design time, reduced construction times, or improvement in quality of the delivered project. At Firm B, organizational strategy relevant to AIT appeared to be loosely defined and much more contingent upon the nature of the current design work in progress. Although utilization of CAD was innovative at Firm B, there did not appear to be a technology strategy for the firm. Acquisition of technology was limited to instances where immediate application and short-term payback were likely.

A common factor at all of the A&E design firms researched was that of the existence or presence of a technology sponsor or champion. In most of the firms, the technology champion tended to be an engineer that became adept at conceiving of long-range plans and then possessing the human relations skills to convince appropriate management that the use of AIT would be a strategic investment for the firm. At Firm A, for example, much of the technology progress within the firm was attributed to a pioneer who championed the adoption of CAD and related technologies before these were generally recognized by the A&E design industry at large.

8. In what ways have leading A&E design firms used advanced information technologies to enhance or strengthen their competitive position?

At Firm A, the ability to demonstrate concepts to a prospective customer in ways not possible before the implementation of various AIT has resulted in a greater likelihood of receiving new project work. Both management and technical personnel were aware of the tremendous capabilities of AIT in terms of conveying informational value to designs. In some instances, a customer can obtain a simulation walk-through of 3D designs, thereby permitting the customer to become part of the active design process. Customer satisfaction has been enhanced through this active participation and has resulted in an increase in repeat business with the same customers. Therefore, customer loyalty has been positively affected.

At Firm B, the use of global networking is providing substantial reductions in time-to-completion for international projects. Architectural renderings can be transformed from paper and physical model to digital form on CAD in days, if not hours. Design files are received via Internet MIME features and then retransmitted to other sites routinely. This has provided a distinct perceptual advantage for Firm B with its current and prospective clients.

At Firms C, D, E and F, an emphasis on intra-company networking permits the rapid exchange of engineering design and project management information. Identification of the specific information desired, however, is still difficult to achieve even with the use of computer networks. At Firm F, subscription news services from satellite transmissions are used to formulate the corporate engineering strategy by monitoring governmental regulations and industrial reports.

9. What impact have advanced information technologies utilized by leading A&E design firms had on their customers?

Management responses at all six A&E design firms indicated that the impact of AIT on their customers has been substantial. In most cases, customers of the firms have certain expectations regarding the capabilities of AIT. Those expectations translate into more sophisticated requests regarding engineering documentation. In virtually all cases, customers expect to receive engineering drawings and related documents in magnetic form. Even customers who have no immediate capability of utilizing the magnetic data typically request that their project files be delivered on floppy diskettes.

At Firm F, the use of AIT has resulted in an increase in customer expectations for receiving electronic data as part of the contractual engineering services. The requirement for delivery of electronic data is determined on a project-by-project basis, but is largely determined by the customer. In some instances, customers expect to receive all documentation in magnetic media form, even if the customer does not have either the equipment or the in-house expertise to utilize the data delivered.

10. What are the organizational obstacles and problems encountered by leading A&E design firms in the acquisition and implementation of advanced information technologies?

At Firm A, the time to develop an AIT plan can be lengthy due to the multiple reviews needed to obtain functional group consensus on equipment and software standards. Management, however, felt that this was an acceptable delay in order to obtain a valid technology plan for the various engineering design functions. This approach also makes integration and support issues less burdensome overall to the company.

At Firm B, acquisition funding appears to be a major obstacle. Although the firm's management generally recognizes the potential benefits obtainable from the use of CAD, thus far, there has not been a major investment in related technologies, such as documents management and information data bases.

Firm C is a large, decentralized firm having several business units and a large number of profit centers. Under this organizational arrangement, selection and implementation of various AIT is left to the discretion of each profit unit. While this may provide some immediate financial benefits to the independent profit units, the overall effect has been negative for the corporation as a whole. Some of the adverse impacts occur because of the

difficulties in developing consistent data standards, optimizing vendor selection and controlling acquisition costs, and developing corporate-level information technology plans.

At Firm D, implementation problems are encountered due to the large numbers of various workstations and personal computers in use in a wide variety of engineering applications. Even with a substantial staff resource to maintain and upgrade the various advanced information technologies, the size of the installed equipment base precludes a quick upgrade or wholesale replacement plan. Specific plans have to be developed to migrate from one generation of technology to the next generation at the same time application training is required.

At Firm E, management reported that a major organizational obstacle related to the inability to develop a common vision regarding AIT among various functional groups. Implementation efforts are often thwarted by shifting of priorities at the managerial level.

At Firm F, financial justification and funding are acquisition obstacles, although not the only reason for the impediment of acquisition and implementation of AIT. The ability to support the AIT requested can also be an obstacle, particularly for more advanced forms of information technology.

11. What organizational problems will leading A&E design firms encounter in the future relevant to the acquisition, implementation, integration, and effective utilization of advanced information technologies?

Firm A's management expressed concern for the future over ownership of the technology plans by various functional groups and the difficulty of deciding where the firm should focus its efforts regarding the use of AIT. It felt that the firm still had some areas where immaturity of knowledge existed about advanced information technologies and how and when they should be used on engineering design projects. Management was also apprehensive about its ability to permit champions to emerge, flourish, and then survive within the environment of a large company.

At Firm B, future acquisitions will likely depend to a great extent upon the firm's ability to effectively manage the problems that arise due to a marginal amount of support staff.

At Firm C, management concerns about the firm addressed the rapid development and introduction of advanced information technologies into engineering applications and Firm C's internal capabilities of absorbing the rapid changes that occur as a consequence. Faster turnover of investment is paramount in order to obtain a cost benefit to using AIT. Networking challenges and the seamless transfer of engineering data are also seen as major challenges to the firm. Increased utilization of 3D CAD design instead of 2D designs is seen as an organization-wide problem that has to be resolved if the firm is to increase its return on investment in a large CAD system.

At Firm F, maintaining the proper mix of AIT is seen as a challenge for the future. Additionally, with more sophisticated technologies now available, more centralized resources will be required to provide adequate implementation and post-implementation needs. Integration of advanced information technologies into an effective suite of tools is seen as a challenge or obstacle. Management at Firm F believes that the short technology life of AIT contributes to the difficulties of acquiring appropriate equipment and resources for the business. In many cases, acquisition has been an "act of faith" without firm data to support the requests for advanced information technologies. Some skepticism about the relative merits of AIT will continue to make acquisitions difficult. Management perceives the investment in AIT as a cost, not an investment, because of the lack of financial data to support claims of productivity.

12. Have there been changes in the organizational structure of leading A&E design firms as a result of advanced information technologies?

For five of the six A&E design firms researched, the appearance and implementation of AIT has resulted in important organizational changes. In all six of the firms, managerial functions have been established to direct and control the financial resources related to AIT. At Firm A, support for the technologies and engineering applications is handled in a central group. Firm A's management is committed to the use of AIT wherever possible and has designed an organizational group to provide the resources to ensure the success of this commitment. At Firm B, downsizing efforts have reduced support staff by one-half, although management recognizes that the firm needs to commit more resources to the use of AIT.

At all six A&E design firms researched, upper management has recognized the impact of AIT. Typically, a managerial function has been created and chartered to develop technology plans in concert with the firm's business strategy. Some of the firms have been more aggressive in their approaches, but all six have at least an organizational group led by a manager of director of computer technology or similar title.

Technology: Questions and Findings

1. What advanced information technologies are now being used by leading A&E design firms in the engineering design process?

Some of the advanced information technologies reported in use at the six A&E design firms visited during the field research are summarized in Appendix D. Computer-aided design tools were the most prevalently used AIT followed by desk-top publishing applications. The traditional engineering tools (see Appendix C) were virtually non-existent at the A&E design firms researched. The disappearance of drafting tables and ancillary drawing instruments has occurred within the past ten years and as a direct consequence of the adoption of CAD technologies. Computer-based word processing has likewise displaced the previously ubiquitous typewriter as the device for producing correspondence, memoranda, parts lists, and other paper-based communications. Combined with modems and communications software, facsimile machines have now become an integral part of project engineering for the receipt and transmission of electronic and paper documents.

Digital scanning and imaging technologies are in use, but only in specific cases whereby image capture can be accurately performed. More frequent use appears to be constrained by the lack of consistency with which images can be captured and translated to a machine-readable form. For some types of projects, notably civil engineering, engineering drawings are scanned and then digitized for input to a CAD system.

At Firm B, the transfer of CAD files between design sites is occasionally conducted through the use of MIME on Internet. Transfer of design drawings from offshore engineering in India to the United States has provided the firm with global design capabilities.

Video conferencing is being used on a frequent basis at Firm A, Firm D, and Firm E to conduct design reviews. In some instances, CAD conferencing is also used to obtain near real-time interaction with clients who have equipment compatible with the A&E design firm.

Lasers combined with 3D CAD equipment has been used by Firm A to produce interior models of complex facilities that need modification. Use of this technology has reduced the amount of labor needed to conduct field measurements and then produce an "as-is" 3D model of the facility. Laser instruments combined with 3D CAD produces extremely accurate dimensional drawings or models that can then be used as the basis for further engineering design.

At Firm F, aerial photography with digitization is used to produce orthographic projections to correct for terrain curvature. Data logging technology, combined with sensors, is also used to capture data about environmental conditions, such as moisture, temperature, and atmospheric pressure. Geographical information systems (GIS) are also used for state and local governmental work relating to "911" (emergency) projects. Global positioning systems (GPS) are used to provide highly accurate data for producing topographical plots.

2. Are there identifiable similarities or differences among the leading A&E design firms in the manner in which they have integrated advanced information technologies?

All of the A&E design firms researched have placed a heavy emphasis upon CAD as the advanced information technology most frequently used in the conduct of their engineering design. Integration of CAD with other AIT has been somewhat fragmented due in part to the differences in information media standards and the differing products available from AIT vendors. Integration efforts have been impeded at all six A&E design firms by the difficulty of installing AIT simultaneously with conducting business in the traditional manner. In all six firms, various advanced information technologies have been implemented with a great deal of internal stress on the organization. In some instances, these stresses reached the point of overload on the organization's ability to absorb change. Abandonment of the technology has been the usual outcome in these instances. Digital imaging technology and electronic documents management are two examples of technologies that could not be readily implemented into the firms' engineering operations.

All of the firms researched now have separate and distinct organizational groups chartered to implement AIT. However, the groups have not been successful in implementing AIT in all cases. At Firm C, for example, different engineering groups have the authority to adopt a specific vendor's technology. This has resulted in a diversity of vendors and information platforms that impedes further improvements in minimizing the number of times that electronic information must be translated. Firm A has been more successful with AIT implementation plans at the regional level due to the fairly rigid adherence to information standards. Operational groups can authorize equipment and software acquisitions at the lower managerial levels, but only within specific vendor guidelines and choices. Firm E has a corporate group whose mission is to develop information and technology standards that the divisions follow. Firm F, like Firm C, has had difficulty in standardizing its various AIT platforms.

3. What have been the benefits of advanced information technologies for leading A&E design firms?

Firm A's managers and engineers reported that the use of AIT had resulted in reduced costs of plant construction since adoption on a large scale. Additionally, a demonstrated and reduced time-to-completion benefit has been verified because of a combination of reasons. First, utilization of AIT has produced shorter project start-up times due to the ability to rapidly utilize previous engineering designs from similar projects. Fewer numbers of engineers and other technical personnel are needed to complete engineering designs. Better quality of designs has resulted and at less cost to the client. The total, installed cost of facilities is significantly less than that even ten years ago, and Firm A's management projects a continuation of declining costs due to further exploitation of the capabilities of AIT. Utilization of electronic "models" has provided the opportunity to consider and evaluate multiple conceptual designs before "freezing" a design. CAD design file capabilities combined with numerical simulation permits a virtual guarantee that a facility can be built to perform "as-designed," not "as-modified" to perform. In short, management and technical personnel were consistent in their responses that the benefits of AIT were well-founded, even if not well-documented through data collection.

The technology manager at Firm B believes that the biggest advantage or benefit of AIT has been to avoid re-creation of the same data, thereby leading to its reuse multiple times.

Management and technical personnel at Firm C, Firm D, Firm E, and Firm F reported similar instances of AIT benefits. In all six A&E design firms, however, no rigorous evaluation of benefits was conducted to support the general benefits cited. Firm A does have documented instances of a financial nature that support reduced costs and reduced time-for-construction of large cogeneration power facilities.

4. Do leading A&E design firms monitor the improvements in productivity for their engineering services?

Generally speaking, none of the six A&E design firms monitor productivity by collecting large amounts of quantifiable data. The indications of productivity are much more general in nature. For example, at Firm A productivity is monitored by historical evaluation of the completion time and construction costs for large engineering projects. Firm A's management reported that due to the use of various advanced information technologies, over the course of approximately the past ten years, project deliverables can be accomplished in about one-half the time and at sixty percent of the cost. These productivity gains have permitted Firm A to expand its investment on a large scale and also to investigate other, exploratory information technologies.

5. How well have leading A&E design firms managed the rapid changes in advanced information technology?

Firm A appears to have a strong, well-run technology plan that outlines the firm's planned projects and the advanced information technologies to support them. Firm B does not have a comparable plan, other than to determine AIT needs on a client-by-client or project-by-project basis. Engineers and managers at Firm C, Firm D, Firm E, and Firm F all expressed disappointment with their internal abilities to manage rapid changes wrought by AIT. Therefore, one of the challenges in the effective use of AIT is to accommodate the unavoidable changes that the organization has to absorb at a rapid pace.

At Firm F, the budgetary process has aided in preventing "crises" or perceptions of needing AIT today versus the ability to defer AIT acquisitions into the future. In brief, the budgetary process serves as a filter and control mechanism to prevent reactionary purchases of AIT.

6. What are the characteristics of leading A&E design firms that have managed well the rapid changes in advanced information technology?

The researcher's conclusion is that Firm A, Firm C, Firm D, and Firm E have been able to manage the rapid changes in advanced information technologies effectively. Characteristics of these firms include: (1) a management commitment to making AIT a part of the work process by supporting funding, training, and acceptance of setbacks and obstacles; (2) a recognition and acceptance by management and technical personnel that a personal effort and commitment to training and learning is required and that there might not be a "payoff" to the individual; (3) an adequate amount of personnel resources devoted to the development, support, and continued implementation of AIT applications.

People: Questions and Findings

1. How have the work processes of architects, engineers, and designers been affected by the introduction of advanced information technologies into engineering design functions of leading A&E design firms?

The consensus among engineering and architectural personnel is that AIT has created a perception, albeit unwarranted, that designs can be produced in less time than that actually required or feasible. This perception is frequently demonstrated by neophyte managers and other managerial personnel who have little or no knowledge of AIT. In some instances, an excess of information leads to additional problems related to timely completion of design projects.

Work processes have been transformed from mostly manual activities using traditional engineering tools to that of an electronic office environment using complex software applications and other advanced information technologies. In the space of approximately fifteen years, the work environment has changed in the basic nature of the team environment for accomplishing projects. Prior to the widespread use of CAD workstations, personal computers, and other computer-based information devices, the work processes for designers, architects, and engineers in A&E design firms revolved around the drafting table. Informal group discussions were conducted daily as an on-going process in order to accomplish engineering designs. With the advent of AIT, the work process is different in that architects, designers, and engineers communicate through networks by transferring files or sharing common design files with overlay capabilities. The traditional communication forums achieved through team reviews and spontaneous meetings have diminished in importance. Additionally, the work processes related to design have also been changed by the use of AIT.

2. How have architects, engineers, and designers influenced the acquisition and use of advanced information technologies in leading A&E design firms?

Generally, at all six A&E design firms, the influence of architects, engineers, and designers has been limited to requests for specific equipment or software to accomplish a given set of tasks or activities. Typically, a request is submitted through user management to the director or manager of the engineering computer applications group, or, in some instances, to the comparable function in the management information systems group. Except for expressing a preference for a specific vendor, the influence on the acquisition has been limited. For the use of AIT, however, the influence is apparent. The architectural and engineering personnel have adopted CAD for their design activities. Other forms of AIT, like scanning, facsimile machines, and micrographic equipment are used on occasion, but their influence is peripheral, not primary.

At Firm A, engineers submit acquisition requests to the computer-aided support group for review and approval. At Firm B, the director of computer services works closely with the requester to provide justification for specific AIT equipment. At Firm C, the chief information officer and staff review requests for conformity with corporate information standards. At Firm D, requests and approvals for AIT are handled on a division-by-division basis. At Firm E, corporate reviews are conducted in order to ensure conformity to published standards regarding various computer-based information technologies. At Firm F, engineers have been influential in determining that the predominant CAD system used is AutoCAD™ software, although the firm's clients can specify other CAD vendors' software for an engineering project, such as MicroStation™ from Intergraph Corporation or CADAM™ from IBM Corporation.

In summary, although architects, designers, and engineers have some influence on the acquisition of various advanced information technologies, it is generally restricted to that of requesting AIT for resolution of specific problems, not actual selection of the AIT. In the area of use of AIT, however, the influence is much more apparent, since designers, architects, and engineers, over time, develop much stronger skills and knowledge about the capabilities of a given information technology and its appropriate use for an architectural or engineering design application.

3. How do leading A&E design firms resolve personnel issues associated with the introduction of advanced information technologies?

At Firm A, the presence and utilization of AIT are so pervasive that technical personnel are presumed by management to accept the technologies in use there. When CAD was relatively new in the early 1980s, some personnel were resistant to the acceptance and learning of the skill sets needed. As more and more personnel became functionally literate in the technology, however, it became apparent that CAD was now part of the work process. Stragglers in adopting technology tools either found other avenues of employment within the firm or left the firm. Today, Firm A devotes a substantial effort and financial resources to provide a constant on-going training program for managerial and technical personnel.

At Firm B, due to downsizing decisions, training efforts have diminished in importance. Personnel obtain additional training in the use of AIT tools through personal efforts or otherwise do without this training.

Firm C's training program focuses on applications in the CAD arena, particularly those related to 3D CAD and data base utilization. New employees are generally expected to already be "CAD literate" on at least one vendor's hardware/software platform. After employment, cross-training needs are met through internal or vendor training provided by the design firm.

Firm D's training program is staffed by employees whose careers have changed from that of AIT users to that of AIT developers for specific engineering disciplines. The firm has investigated the possibility of outsourcing of training, but has found that this option is most appropriate for fundamental or basic training of skills, but not for the more advanced training required to fully exploit AIT.

At Firm E, training receives a substantial commitment from the firm's upper management. Having evolved through several generations of CAD, the firm's management recognizes the continuing need for on-going training for technical personnel.

Like Firm D, Firm F's in-house training support staff are obtained from the user ranks, recruiting those users who demonstrate more advanced mastery of the technology application and who also exhibit teaching skills for conveying this knowledge to their peers. A "middle of the road" approach is used in dealing with personnel who demonstrate resistance or inability to learn and adopt information technology as part of their abilities.

In none of the firms was termination of an employee due to his or her inability to function within a technology environment used for eliminating non-AIT users. Instead, reassignment to other tasks, although perhaps of lesser stature, was the process for dealing with personnel who could not develop new skills.

4. What changes have occurred to management functions in leading A&E design firms due to the acquisition and implementation of advanced information technologies?

At Firm A, Firm C, Firm D, Firm E, and Firm F, additional management levels and functions have been added to the organization in order to monitor and control resources

allocated to the support of engineering functions using advanced information technologies. At Firm B, there has been no increase in the numbers of management levels involved in the acquisition and implementation of AIT, but there is a single manager charged with this responsibility. In general, the traditional management functions of controlling, directing, organizing, and staffing have not changed substantially. The nature of the skill sets required by managers of AIT has changed from those formerly required. In addition to engineering design and management functions, the management role now includes the requirement for knowledge of computer-based information systems and the complexities of utilizing them effectively. In brief, management's role and responsibilities have been made more intensive and complex.

Task: Questions and Findings

1. **Are there identifiable similarities or differences among the leading A&E design firms in the manner in which they have integrated advanced information technologies into their work processes?**

For all six of the A&E design firms researched, Computer-Aided Design was the first implementation of advanced information technology. Since CAD was initially intended to replace the manual drafting boards, it was seen as a low-level technology, even though the cost initially was on the order of $40 to $50 thousand per seat. Word processing for improving administrative tasks also occurred during the late 1970s and early 1980s.

At first, these two technologies were separate due to the differences in job classifications held by technical staff and secretarial and clerical personnel. As CAD evolved, however, many of the tasks previously accomplished by the secretarial pool were absorbed by engineers and designers. For example, formerly bills of material and parts lists were typed by clerical personnel, then reviewed by designers or engineers, and then approved by project leaders or managers. The engineer's role was one of technical validation and perhaps approval. The task of data entry was assigned to the office clerical personnel. As CAD databases were implemented as part of their drafting capabilities, it became apparent that the data entry activities were already being accomplished during the design/drafting process and that a separate typing activity could be entirely eliminated.

Beyond exploiting Computer-Aided Design technologies for engineering design activities, Firm A is currently developing, in-house, a computer-based project management software platform to further exploit the benefits of AIT. Firm A's management is convinced of the benefits that have accrued from CAD, and now seeks to add a higher level of project control to large, on-going engineering projects.

2. How did the use of advanced information technologies affect traditional architectural and engineering analysis, design, and documentation tasks?

For all six A&E design firms, it was reported that the use of AIT has improved the analysis and design tasks of architectural and engineering designers by providing an alternative means for them to accomplish the necessary computations needed. The speed of computer-based forms of AIT provides a distinct advantage in terms of reducing the drudgery of iterative analyses that formerly consumed large amount of engineering resources.

Documentation tasks are made considerably easier by eliminating redundant activities since, in the case of CAD, concepts become designs, which later become plans, which later still become permanent records of the facility. Reduction of time and engineering labor has been positively affected through the use of other forms of AIT, like scanning of documents, rapid plotting capabilities, and information networks.

3. How has the use of advanced information technologies affected the skills required by the individual architect or engineer?

Skill requirements for architecture and engineering personnel have been increased commensurate with the widespread implementation of AIT. In addition to the technical knowledge requirements, engineering and architectural personnel have had to acquire computer competency skills in order to utilize the technologies. These knowledge requirements go far beyond the minimal computer skills of new users. Detailed knowledge of the use of AIT to accomplish specific job and project activities is now expected by A&E design firms. In particular, job specialization has been diminished by the implementation of CAD.

Job requirements for designers and engineers are less distinct with the use of CAD. In some applications, it is difficult to distinguish between design and drafting. Prior to the use of CAD, job tasks for designers and engineers were highly differentiated between drafting and engineering analysis and design. Assignment of job responsibilities within a set of project activities was discrete and distinct with relatively little overlap. After the adoption of CAD, however, job responsibilities became blurred, often with the designer performing some of the tasks traditionally held by engineers.

Information: Questions and Findings

1. What changes have occurred within leading A&E design firms due to the availability of information resulting from the use of advanced information technologies?

Advanced information technologies, generally, have reduced the amount of time needed to complete architectural and engineering designs, according to the empirical data collected at the six A&E design firms. The lead time for starting up the design phase of projects has been reduced, thereby permitting more evaluation of alternatives and conceptual layouts. Ordering ahead of schedule can be more readily accomplished through the use of standardized protocols that are now essentially embedded in the information infrastructure of the A&E design firms.

The need for allocation of time and resources previously required at the end of projects for rework of field errors and design changes has essentially disappeared, according to the evidence obtained from the management interviews at the six A&E design firms. This has resulted in additional time and cost savings for the client and has contributed positively to the client's perceptions of the A&E design firm's ability to design and/or manage a large construction project.

2. Has the use of advanced information technologies by leading A&E design firms affected the method of handling "as-built" information?

"As-built" engineering information refers to the concept of final documentation for a facility as it was actually constructed. Usually, design changes occur in the course of a project due to customer directives or field errors. Original design documents, then, are different from the final, as-built construction. Design information in the form of drawings, specifications, parts lists, and other contractual information requirements must then be updated in order to deliver "as-built" documentation to the project client. In some instances, the cost of updating design documents to "as-built" condition could represent five to fifteen percent of the engineering costs for a project. Therefore, "as-built" documentation represents an important cost to the project for both the A&E design firm and, ultimately, the customer.

Firm A has developed procedures using AIT that has removed much of the costs of delivering as-built documentation. From the inception of the project, engineering documents procedures and standards are utilized throughout the project. Using a documentation protocol, changes are logged in the field as they occur. Revisions to all documentation occur as an on-going process. At the completion of the project, the final documentation delivered to the client is "as-built" documentation; that is, documentation that represents faithfully the actual construction of the facility. Adherence to fairly rigid procedures has caused Firm A to increase its dependence on various forms of AIT. This dependency has also served to change the organizational structure and processes from their prior states.

At Firm B, "as-built" information is not usually provided, since the primary emphasis is on conceptual architectural renderings of the proposed building design. In some instances, physical models of a facility are constructed, but usually during the course of the project, the model becomes outdated. With the use of CAD and related technologies, Firm B can deliver as-built designs, but the firm does not have sufficient equipment and resources to provide this capability for all projects. For most projects, actual construction is handled by a larger construction firm and "as-built" information requirements, if any, are placed upon this firm.

At Firm C, "as-built" documentation is delivered to the client as a separate set of documents from the design documents. Firm C's management is planning to make the delivery of "as-built" documentation a seamless operation, but has not yet achieved this goal.

Firm D is similar to Firm A in its treatment of "as-built" documentation, but has not yet instituted a comprehensive engineering documentation system to accommodate this goal.

Firm E is developing plans to improve the "as-built" documentation process, but has not yet achieved the capabilities of Firm A. At the present time, documentation is produced in phases: design documents, construction documents, and as-built documents. Management is aware of the possibility of combining the construction and as-built documentation phases, but has not yet accomplished this.

Firm F does not appear to have a stated policy concerning "as-built" documentation. This documentation is produced as a separate process: if the customer desires "as-built" documentation, then design documents will be updated, but as a separate engineering activity. Usually, separate engineering activities are undertaken to accomplish this and usually after the facility checkout has occurred. Markups of field documentation are utilized to perform the as-built updating.

3. Are there evidences of "success" among leading A&E design firms due to the increased availability of electronic information?

Firm A's management and engineering personnel believe that repeat business from customers is evidence of their "success" in terms of increased availability of information due to AIT. Also, at Firm A, "success" could be evidenced by producing what was proposed. Evidences cited included: a reduction in the amount of rework needed at the end of a project, a reduction in the number of personnel needed to accomplish the design, the absence of drafting boards and other traditional engineering design tools of a manual nature, and a reduction in the number and severity of interference problems typically encountered during the construction phase of a project.

Another example of "success" at Firm A is that of vendor partnering that has become an accepted business practice. Sharing of electronic information provides mutual benefits, especially in instances of application of technologies. Problems and opportunities can be addressed from both the vendor and the user perspective, rather than in the traditional adversarial manner.

The director of computer services at Firm B felt that "success" could be stated in terms of its participation in technology conferences and special interest groups.

Firm C's management believes that "success" could be stated in terms of the reuse of the information. The more often information can be reused without being reentered into various computer-based systems, the higher the degree of "success."

At Firm D, the customer's perceptions and satisfaction was given as a basis for evidence or "success" for increased availability of electronic data.

At Firm E, the ability to trace the electronic deliverable through the engineering cycle would constitute "success" in terms of increased information availability. At Firm E, the legal document is still not the electronic document and this could be impeding their achievement of "success" as management has defined it. Reproduction of electronic information in paper form is still used. Archiving by photographic methods, such as microfiche or microfilm is used to provide an historically-accurate, legal document. Often, the paper documents are preserved by archiving these as well.

At Firm F, like Firm E, archiving of paper documents is still practiced. For some projects, engineering information can exist in three forms, all of which may be at different version levels: paper, magnetic, and film. To resolve the difficulty of archiving information in three different systems, a single archive method is used. All project information in any form is archived in boxes at an off-site warehouse. The evidence of "success" at Firm E in terms of information availability is linked to the ability of the project engineer to restore or recover information in a manner that can result in efficient reuse.

4. How are information data bases currently being used by leading A&E design firms?

None of the six A&E design firms researched are currently utilizing electronic data interchange (EDI) technology. Third party data bases, such as electronic catalogs, however, are being used. Typical examples of on-line electronic catalogs currently in use at the six A&E design firms are R. S. Means and Company and Sweet's catalogs. These catalogs provide industry-wide pricing information that A&E design firms use to develop project proposals with standardized cost information.

Additionally, on-line news services are being used. On-line news services are obtained by subscription in order to monitor industry and governmental regulations and proposed projects. By monitoring various firms in different industries, the A&E design firms are able to predict the likelihood of an invitation to bid and thereby gain a time advantage over their architectural or engineering competitors.

Competency Indicators for Architecture and Engineering Design Firms

The expert Delphi panel was solicited for its opinions regarding competency indicators for A&E design firms. Fifteen indicators were compiled from the responses for developing a qualitative instrument for evaluating A&E design firms in their use of advanced information technologies. These competency indicators are listed in their entirety in Appendix L and are discussed individually below in terms of the research findings. Although use of the instrument can be highly subjective, the list of indicators provides a method of judging or assessing competency for practitioners and managers, both within architecture and engineering design firms, and by users of A&E design services.

Examples of some of the research findings are provided in order to demonstrate the use of the qualitative instrument and to show the benefit of using a competency indicators assessment as a means for screening or selecting an A&E design firm, based on its effectiveness in terms of advanced information technologies. Examples of indicators of the degree of competency at the six A&E design firms examined are provided here in order to demonstrate the relative competency of the six A&E design firms researched. Additionally, discussion of how the competency indicator instrument can be practically used for internal assessment of a firm's competency in the use of advanced information technologies is presented.

1. An appropriate organizational structure is present for the support of advanced information technologies.

Firm A, Firm C, Firm D, Firm E, and Firm F have a specific organizational group whose primary function is to support the use of advanced information technologies in architectural and engineering design. Firm B has personnel assigned to this function, but there did not appear to be sufficient numbers of personnel assigned to the support function to have a viable support group. Management at Firm B expressed concerned over this, but recognized that due to downsizing, support and development of advanced information technologies were limited to on-going projects.

It is interesting to note that these functional groups did not exist as recently as ten years ago. In the past decade, the impact of advanced information technologies has resulted in sizable personnel allocations to acquire, implement, develop, and manage various aspects of these technologies. These groups have become part of the corporate memory in the sense that they are responsible for ensuring that the rest of the organization can create, utilize, and retrieve architectural and engineering design information.

2. A training program exists to provide appropriate skills and knowledge to user personnel and the training program utilized by the organization.

A formal training program for personnel in the use of advanced information technologies was present and in active use at Firm A, Firm C, Firm D, and Firm E. Firm A provides an additional incentive to its technical personnel by incurring meal expenses for attendees at periodically scheduled hour-long training sessions. Participation is voluntary, but the use of the meal allowance has resulted in frequent attendance by the employees. Management felt that the investment had yielded both the intent of the program and was evidenced by more active involvement of the users of AIT at Firm A.

Firm B did not appear to have a formal training program. Training in specific AIT is provided by the firm, but need must be identified prior to a commitment by management to provide off-site or vendor-oriented training.

Firm F has a training program, but it did not appear to be a part of management's overall long-range planning. Management at Firm F expressed concern over the continuing costs of advanced information technologies and felt that much of the training conducted in the past was ineffective and too lengthy. There was some attempt to identify training needs and to shorten the learning curve for technical personnel by eliminating excessive training in areas not needed or by focusing the training to specific skill areas.

3. Long-range technology planning is conducted on a regular, periodic basis at sufficient intervals to maintain currency with advanced information technology changes and innovations.

Firm A, Firm C, Firm D, Firm E, and Firm F have long-range technology planning. Technology planning at Firm A and Firm D is seen as a key strategic factor in their business plans. Firm B appears to have no long-range technology planning. Acquisitions of advanced information technologies are predicated upon identification of need and then subsequent justification within the scope of a design project. Unless the project can be used to justify acquisition of a specific advanced information technology, then purchase is deferred or delayed, even though an early acquisition might result in critical advantages and benefits to the firm at a later date. Firm F appeared to be less aggressive in terms of technology planning, but technical management expressed their concern for more executive management attention in this area. Technical management is aware of the likelihood that Firm F is probably behind some of its competition in terms of adoption of AIT.

4. Technology planning focuses on the integration of all architecture and engineering disciplines within the firm's business objectives.

Firm A, Firm C, Firm D, and Firm E have formal technology planning schedules that are used to develop long-range integration and resource allocation plans. Firm B did not appear to have a formal technology planning agenda nor one that addresses the total technical, information needs of the organization. Firm F has a formal technology plan but recognizes that it needs to become more adept at translating project technology needs with the long-term technology plan.

Only at Firm A, Firm C, Firm D, and Firm E, did there appear to be a concerted effort to define information needs in terms of integration of the disciplines used at the A&E design firm. Advance information technology planning at Firm B and Firm F appeared to be more ad hoc in nature, based more on defining immediate needs to accomplish a particular project rather than evaluation of the project's AIT requirements against the firm's long-term AIT plan.

5. The level of technology embraced is consistent with the organization's mission and goals.

There appeared to be a close match among the organization's mission, goals, and focus at Firm A, Firm B, and Firm F. This may, at first, seem paradoxical considering the research findings for Firm B and Firm F in the previous competency. However, Firm B and Firm F appear to be effective in terms of delivering architectural and engineering designs and information to their clients. Although the latest AIT were not in evidence at Firm B and Firm F, there did appear to be a reasonably current set of advanced information technologies to accomplish the needs of their clients. Firm C, Firm D, and Firm E, on the other hand, appeared to have acquired various advanced information technologies for the purpose of evaluating these for future plans. A large amount of personnel and resources seemed to be allocated to the investigation of these advanced information technologies, although the prospects for future acquisition and implementation on a larger scale might be tenuous.

6. A recognition program exists to recognize and reward personnel for their achievements and accomplishments related to the effective use of advanced information technologies.

Recognition programs for personnel exist at Firm A, Firm C, Firm D, Firm E, and Firm F. The recognition programs at Firm A and Firm D appeared to include reward as a part of the program of recognition. Firm B and Firm F did not appear to have recognition programs per se, although some evidence was available at Firm F to support the opposite conclusion.

7. Proactive participation in industry or vendor-supported user groups and conferences is encouraged by the organization's management.

Technical management at Firm A, Firm B, Firm C, Firm D, and Firm E participates actively in industry or vendor-supported user groups and conferences. Firm F did not appear to be aggressive in this respect, although there was evidence of some participation. The degree of participation did not appear to be on the same scale as that at the other firms. This may be due, in part, to the nature of the industry segment in which Firm F operates. Participation in user groups and conferences tended to focus on trade groups and conferences, and not on those for advanced information technologies.

8. **Standards related to the proper creation, archiving, and retention of information are documented and utilized by architecture and engineering personnel and supported by management.**

Firm A, Firm C, Firm D, Firm E, and Firm F utilize published standards relating to the creation and archiving of architectural and engineering design information. Firm A, Firm C, and Firm E appeared to have active programs to maintain the currency and relevance of the information standards. Firm B did not appear to have a published standard although there is a protocol for retention of magnetic information. The use of personnel as part of the organization's memory serves as the protocol for creation and archiving of information. Retrieval of the information at Firm B is highly dependent upon personnel to remember enough data attributes to locate and restore magnetic information. The existence of large numbers of paper-based files and other documents indicates that recovery of data is problematic. There did not appear to be a formal procedure for the archiving of information, nor any reasonable assurance that critical information could be retrieved and restored in a timely and accurate manner. Technical management at Firm F is actively reviewing its workflow and documents management problems.

9. **Management is qualified in the use and capabilities of advanced information technologies, both internal and external to the organization.**

Technical personnel at Firm A, Firm B, and Firm F were critical of management at their respective company in terms of management's ability to use advanced information technologies. At Firm C, Firm D, and Firm E, criticism was less overt, and operational management at these firms appeared to have competencies in the use of the advanced information technologies. A key criticism that was frequently expressed during the field interviews with technical personnel was management's seeming unawareness of the labor and system resources needed to accomplish project design work in a specified time period. Since much of the information activity using advanced information technologies is invisible, criticism of management's indifference or unawareness of information requirements and the efforts to accomplish tasks with these technologies appeared to be substantial and prevalent among all six A&E design firms.

10. Utilization of advanced information technologies focuses on the total design process, from concept, through design, and construction.

Firm A, Firm D, and Firm E have integration and development programs to ensure that long-term technology solutions focus on the total information life cycle. Management at Firm A and Firm D appeared confident that this was a viable, although difficult, challenge for their respective firms. Firm B, Firm C, and Firm F did not appear to have yet developed a concept of a life cycle for architectural and engineering design information.

Management at Firm A, Firm D, and Firm E is convinced that further savings and benefits can be extracted from the proper integration of advanced information technologies. The stated goal is to have a relatively seamless transfer of design information from client to the A&E design firm, from supplier to the A&E design firm, from the A&E design firm to its contractors, and finally, from the A&E design firm to its customer. The execution of the concept appears to be impeded by the general lack of industry-wide standards that occurred during the early years of AIT and by the presence of legacy systems that are still productive and, therefore, not yet retired from active use.

11. Information is deliverable to the firm's client in a timely manner and in the proper information media and format.

Although external sources for verification of this indicator would be desirable from a customer's perspective, operational management at Firm A, Firm C, Firm D, Firm E, and Firm F felt that part of their respective firm's strategic advantage is the ability to deliver information to their clients in any form desired. In most instances, customers are now expecting to receive all architectural and engineering design information in magnetic and hard copy form, even though the customer might not necessarily have the proper hardware, software, and trained personnel to utilize the information. Technical personnel at these firms, however, were less certain of the ability of their firm to deliver information to a customer in a timely manner, due to the difficulty of defining and adopting specific customer information requirements. Firm B did not seem to have the same pressures to deliver magnetic information to customers, since it is relatively new to the use and adoption of advanced information technologies. Firm B does, however, deliver hard copy and film media if desired by the customer. External service bureaus are often used to provide this service to its customers, since internal resources are limited. In some cases, a physical model of the architectural concept or design is also provided to the customer, if required.

12. Archived information is organized in a manner such that specific project information can be retrieved in a near real-time manner and in the proper information media and format.

Firm A, Firm C, Firm D, and Firm E have procedures for archiving architectural and engineering design information so that the information can be retrieved rapidly and reproduced in the required information media and format. While all six of the A&E design firms utilize a variety of media, including magnetic, film, and paper, Firm B and Firm F did not appear to have a procedure or policy addressing the archiving of information at the time of project closing or other milestone event. Later retrieval of the information and restoration in the proper media and format could be burdensome and costly.

13. Advanced information technologies are leased or purchased based upon specific technology planning requirements.

A critical issue relating to the use of advanced information technologies is the length of their useful life. Management at Firm A, Firm C, Firm D, and Firm E expressed their concern over this issue. These firms tend to acquire AIT by leasing rather than by outright ownership through capital purchases. This provides these firms with the flexibility of migrating to another vendor or to another platform if market conditions mandate or suggest this. Another advantage relayed by management at these firms is that obsolescence issues have been diminished through short-term leasing. Maintenance and support for AIT has also been favorably addressed through leasing. Therefore, it appears that a competency indicator for A&E design firms may be represented by its purchasing policy regarding AIT. Firm B and Firm F tended to purchase equipment based upon specific project needs and the ability of a given project to support or fund the acquisition. The disadvantage to these firms is that of the real obsolescence of the equipment and related software acquired.

14. Security and backup of information is ensured through periodic project reviews and audits.

Periodic project reviews are performed at Firm A, Firm C, Firm D, Firm E, and

Firm F. Firm B did not appear to have a periodic project review and audit procedure relating to the use of advanced information technologies. Backup of information was reported for all six A&E design firms. In most instances, audits are internally performed, although in the case of Firm F, work for various governmental agencies requires periodic external audits.

Although backup of information is typically not an issue until information is lost or corrupted, the effective use of advanced information technologies suggests that firms cannot be competent in this area unless there is a protocol or procedure to accomplish information backups consistently. Much of the work related to security and backups is invisible to the firm's customers except as identified through external audits. The need for effectiveness in this area is frequently overlooked or diminished by management.

15. The advanced information technologies used produces demonstrated benefits to the firm's clients.

Both management and technical personnel at all six A&E design firms expressed their desire to deliver value to their clients by the effective use of advanced information technologies. In some instances, this value is based upon the customer's perceptions, real or not, but important nonetheless. Management at Firm A, Firm D, and Firm E has made strong commitments to determining what actually constitutes value to their clients by engaging them in discussions and review sessions that involve the active use of advanced information technologies.

Cardinal Ranking of A&E Design Firms

Although cardinal ranking of the six A&E design firms is a subjective process, the use of the competency indicators can provide prospective customers of A&E design firms a basis for comparison. It should be noted that the fifteen indicators are not necessarily complete nor comprehensive in all respects. The fifteen competency indicators were obtained from solicitation of the expert Delphi panel and architecture and engineering practitioners, and therefore, are normative indicators. The objective here is to demonstrate how the competency indicators can aid in determination of an A&E design firm's competency in the use of advanced information technology from all of the perspectives included in the research model: organization structure, personnel, task, technology, and information.

All competency indicators are weighted equally, each indicator equal to one point. Scoring of the competency indicators, however, could be further weighted or scaled in order to provide additional granularity. For the present research, however, all fifteen competency indicators were given equal weight, and cardinal ranking was based upon the relative numerical score in points obtained by the A&E design firms. For example, Firm A was ranked as most competent, by receiving the highest score out of a possible fifteen points, and had the highest score out of the six A&E design firms. A cardinal ranking based upon evaluation of the six A&E design firms using the competency indicators is provided below in Figure 12.

As seen in the ranking, three firms received the highest score of thirteen out of a possible fifteen points. This is not surprising, considering that all of the A&E design firms researched were submitted by various members of the expert Delphi panel as being representative of leading firms in the use of advanced information technologies. The summary does show, however, that discrimination among a set of A&E design firms is possible using the competency indicators as a qualitative assessment instrument. The benefits of the instrument, then, are demonstrated for practitioners and researchers of advanced information technologies.

Ranking in the Use of Advanced Information Technologies

Rank	Firm	Score
1	Firm A	13
1	Firm D	13
1	Firm E	13
4	Firm C	11
5	Firm F	8
6	Firm B	3

Figure 12.

The reader should be cautioned that a lower ranking in the cardinal scale does not imply "incompetence." A lower ranking for a firm implies that other A&E design firms with higher rank positions may demonstrate greater degrees of competencies or a broader range of competencies. The reader will recognize the difficulty of absolute rankings using qualitative, empirical data, but in the absence of validated deterministic instruments, qualitative assessment can still provide answers to questions of competency in the use of advanced information technologies. The use of the competency indicators instrument does provide a gauge by which an A&E design firm can be assessed against a set of criteria that were proposed by a panel of experts in a Delphi process. These competency indicators, then, can serve practitioners and managers as an instrument for either internal self-assessment or for use in assessing other competing A&E design firms.

Chapter Summary

Chapter 5 provided a summary of the research findings obtained from the six architecture and engineering firms investigated. The research findings were discussed using the conceptual research model as a framework and the questionnaire as the basic research instrument. Additionally, research findings in terms of the competency indicators were presented for the six A&E design firms examined. Chapter 6 presents the empirical research findings for the six A&E design firms in terms of Huber's fourteen propositions in his theory of the effects of advanced information technologies.

CHAPTER 6

HUBER'S PROPOSITIONS AND RESEARCH FINDINGS

Chapter Objective

The objective of Chapter 6 is to present Huber's propositions relating to advanced information technologies and the research findings in terms of these propositions. The research findings for the A&E design firms are presented and discussed for each of the fourteen propositions in Huber's theory. A summary of Huber's definitions and some of the fundamental concepts relating to advanced information technologies are first presented in order to provide the basis for discussion of the propositions and their relevance to the research findings.

Advanced Information Technologies

Huber defines *advanced information technologies* as "devices that: (a) transmit, manipulate, analyze, or exploit information; (b) in which a digital computer processes information integral to the user's communication or decision task; and (c) have either made their appearance since 1970 or exist in a form that aids in communication or decision tasks to a greater degree than did pre-1971 forms" (Huber, 1990, p. 48). The selection of 1970 as the chronological division is somewhat arbitrary (Huber, personal communication, 1994), but this year corresponds approximately with the widespread use of minicomputers. This date also precedes the introduction of microprocessors that led, ultimately, to the possibility of the development of the personal computer with its pervasive influences upon organizations. A list of advanced information technologies that fit Huber's definition are provided in Appendix D. These advanced information technologies were observed at one or more of the A&E design firms researched and were discussed in the technology section in Chapter 5.

Huber further partitions advanced information technologies into two major groups. In the first group, *basic characteristics* refer to data storage capacity, transmission capacity, and processing capacity. Largely as a result of their digital computer technology, advanced information technologies usually provide higher levels of these basic characteristics (Culnan and Markus, 1987).

The second group of characteristics or properties, refer to either (1) communication or (2) decision aiding attributes of advanced information technologies. Communication properties refer to those that facilitate the ability of the individual or organization to:

(a) communicate more easily or less expensively across time and geographic location (Rice and Bair, 1984);

(b) communicate more rapidly and with greater precision to targeted groups (Culnan and Markus, 1987; Sproull and Kiesler, 1986);

(c) record and index more reliably and inexpensively, the content and nature of communication events; and

(d) to more selectively control access and participation in a communication event or network (Culnan and Markus, 1987; Rice, 1984; Huber, 1990).

With respect to *decision aiding characteristics*, the properties include those that facilitate the ability of the individual or organization to:

"(a) store and retrieve large amounts of information more quickly and inexpensively;

(b) more rapidly and selectively access information created outside the organization;

(c) more rapidly and accurately combine and reconfigure information so as to create new information (as in the development of forecasting models or financial analyses);

(d) more compactly store and quickly use the judgment and decision models developed in the minds of experts, or in the mind of the decision maker, and stored as expert systems or decision models; and

(e) more reliably and inexpensively record and retrieve information about the content and nature of organizational transactions" (Huber, p. 50).

Therefore, Huber's proposed theory includes only (a) the use of computer-assisted communication technologies and (b) the use of computer-assisted decision-making technologies. His theory expressly does not include the use of computer-assisted production technologies or transaction-enabling technologies like computerized billing systems (Huber, 1990, p. 49). Huber's definition, with its constraints, is directly applicable to the advanced information technologies being used by large A&E design firms. There are some exceptions to this, however, depending upon how a specific advanced information technology is used.

Appendix D provides a list of advanced information technologies that the researcher encountered in the field research at various A&E design firms. In all cases, these technologies meet all constraints of Huber's criteria to be considered forms of advanced information technology. In some instances, an argument could be made for excluding a given technology, but conversely, an equally sound argument can be made for including the same technology. The distinction between the two arguments depends upon the specific application of the technology in an organization. As an example, computer-aided design technology and its various forms could be considered to be a production-aiding technology in the case of producing engineering drawings and in this case, the technology could be excluded by Huber's definition of what constitutes an advanced information technology. Conversely, computer-aided design as a technology can also be categorized as possessing either (1) communication-aiding properties or (2) decision-aiding properties whenever the technology is used to transfer information between or among individuals, or whenever the technology is used to assist in making engineering design decisions. In this application, computer-aided design technology would satisfy Huber's criteria. Therefore, the researcher used a conservative approach and included all technologies that satisfied Huber's definition of advanced information technologies.

Another criterion of advanced information technology that Huber addresses is that of the distinction between data and information. Huber chooses to categorize both data and information into the same conceptual grouping, although he does recognize the traditional information systems distinction between the two. Data are stimuli and symbols, whereas information is data conveying meaning as a result of reducing uncertainty. For Huber's theory, however, the distinction between the two is undefined.

Huber also recognizes the existence of commonly-held misconceptions about advanced information technologies. First, a misconception exists that holds that advanced information technologies are either inferior or superior to traditional technologies. This impression is erroneous because the properties of advanced information technologies may be either more important or less important than the properties of traditional technologies. A specific use of an advanced information technology may have undesirable effects (Culnan and Markus, 1987; Markus, 1984; Zuboff, 1984). In fact, according to Huber, there is evidence that traditional technologies frequently score higher than their corresponding replacement advanced information technologies on the dimensions of acceptability, ease of use, and richness (Culnan and Markus, 1987; Fulk, Steinfield, Schmitz, and Power, 1987; Trevino, Lengel, and Daft, 1987). Therefore, Huber maintains that, for these reasons, the use of advanced information technologies will not eliminate the use of traditional technologies. The adoption of advanced information technologies by organizations, however, will occur, Huber feels, whenever their properties can enhance individual or organizational effectiveness, and if their adverse effects are relatively weak.

The availability of advanced information technologies leads to an increase in the communication and decision-aiding opportunities for the user. Over the long run, the quality of these processes is improved. Organizations, through their constituent members, learn through experience which communication and decision-aiding technologies are likely to satisfy their needs, and thereby adopt them. Huber cites several field studies that support this belief.

Another misconception concerns the impression that advanced information technologies are direct substitutes for traditional technologies. Huber maintains that advanced information technologies are frequently adopted as supplements and complements to the traditional technologies, rather than as substitutes. As an example, electronic mail is frequently used as a communication-aid to confirm in text form what might have been oral or spoken communication. Image transmission devices might be used to distribute drawings after individuals have had the opportunity to review them. Overall, Huber feels, advanced information technologies increase the number of options available to the user for communication or decision-making.

The final erroneous impression deals with the assumption that only organizations that are driven by economic rationality are likely to adopt advanced information technologies compared to those organizations that are highly political or power-driven. Although he presents no research evidence in his writing (1990), Huber cites three observations that tend to support this premise. First, many organizations are competitive and their survival depends upon adoption and proper utilization of advanced information technologies. Second, political or power-driven organizations can also exist in highly competitive environments and here, managers must attempt to maximize their own competitive efforts by at least appearing to meet the goals of resource controllers (Burgelman, 1982; Kelley, 1976; Shukla, 1982). Even in these organizations, justifications of the technologies acquired are frequently tied to financial or technical rationale. The third observation is that in nearly all organizations, fulfillment of the organization's goals effectively, contributes to a manager's reputation within the organization (Daft, Lengel, and Trevino, 1987). Therefore, even in political or power-oriented organizations, acquisition of advanced information technologies occurs, although for different motivations. "Together, these observations suggest that even though power and politics influence organizational design, intelligence, and decision making, so too do information technologies; *for advancement of their own interest, organizational participants will use advanced information technologies in ways that increase their effectiveness in fulfilling organizational goals*" (Huber, 1990, p. 52).

Research Findings and Huber's Propositions

Huber has proposed fourteen propositions to support the constructs of his theory of the effects of advanced information technologies on organizations. Empirical evidence was found for some of these propositions that aids in understanding the impact of these technologies on architecture and engineering design firms, as well as organizations, in general. Each of the propositions and the relevant aspects of the research findings for the A&E design firms are discussed below, following additional foundation material concerning advanced information technologies. A complete listing of the fourteen propositions is included as Appendix G for the convenience of the reader. For purposes of conducting the field research, the propositions were changed to questions, rather than using the propositional form of the statements. This was done to avoid providing either a positive or negative response during the interviews, since expository responses were desired in all instances in order to obtain the information needed for supporting or refuting of Huber's propositions.

Huber's theory of the effects of advanced information technologies focuses on a central question: "What are the critical characteristics of advanced information technologies that might cause these technologies to have effects on organization design, intelligence, and decision making different from the effects of more traditional technologies?" (Huber, 1990, p. 49). The independent variables of an organization, according to Huber's theory, are organizational design, intelligence, and decision making. A diagram of Huber's dependent variables is presented as Figure 13 on the following page and in Appendix K. This diagram is presented in order to show the overall structure of the dependent variables in relationship to the independent variables of organizational design, intelligence, and decision making.

HUBER'S MODEL OF EFFECTS OF ADVANCED INFORMATION TECHNOLOGIES ON ORGANIZATIONAL DESIGN, INTELLIGENCE, AND DECISION MAKING (1990)*

---------- DEPENDENT VARIABLES ----------

Design Variables (Subunit Level)	Design Variables (Organizational Level)	Design Variables (Organizational Memory)	Performance Variables
Participation in decision making (1)	Centralization of decision making (4,5)	Development and use of computer-resident data bases (8)	Effectiveness of environmental scanning (10)
Size and heterogeneity of decision units (2)	Number of organizational levels involved in authorization (6)	Development and use of computer-resident in-house expert systems (9)	Quality and timeliness of organizational intelligence (11)
Frequency and duration of meetings (3)	Number of nodes in the information-processing network (7)		Quality of decisions (12) Speed of decision making (13, 14)

Note: The related propositions for each design or performance variable are shown in parentheses.

*George P. Huber, "A Theory of the Effects of Advanced Information Technologies on Organizational Design, Intelligence, and Decision Making," Academy of Management Review, 1990, Vol. 15, No. 1, Table 1, p. 48.

Figure 13.

Huber views the organization, in terms of the theory he proposes, as four categories of dependent variables; namely, (1) design variables at the sub unit level; (2) design variables at the organizational level; (3) design variables as organizational memory; and (4) performance variables. To support such a theory, Huber proposes fourteen propositions that could become part of an integrated theory of advanced information technologies. Although the categorization of these propositions into four groups was primarily for pedagogical purposes (Huber, 1990, p. 52), the first three groups portray the effects of advanced information technologies on organizational design at (a) the sub unit structure and process, (b) organizational structure and process, and (c) organizational memory. The fourth group, performance variables, deals with the effects of advanced information technologies on organizational intelligence and decision making. Huber defines *organizational intelligence* as "the output or product of an organization's efforts to acquire, process, and interpret information external to the organization" (Huber, 1990, p. 52). Intelligence, then, is used as an input to the organization's decision makers.

Huber's theory does not explicitly incorporate the following variables: (a) horizontal integration, (b) formalization, (c) standardization, and (d) specialization. Huber comments briefly on these organizational design variables briefly, but recognizes their importance to organizational researchers. *Horizontal integration* refers to the use of communication structures and processes for facilitating joint decision making among multiple units or individuals. *Formalization* refers to the use of standards, particularly whenever behavioral norms cannot be depended upon to provide the desired outcome. *Standardization* is used to reduce the variability of organizational processes. *Specialization* due to the use of advanced information technologies can lead to either: (1) additional job categories or to (2) a reduction in job categories within an organization.

Each of the fourteen propositions comprising Huber's theory of advanced information technologies is discussed in order to convey the essence of each to the reader. Integration of

Huber's propositions within the framework of the research model is also presented through integration of the empirical data collected during the field research.

Although there will be exceptions to relationships suggested by a proposition, across a large number of cases, *ceteris paribus*, there will be the tendency for the effects of the proposition to be observed if the premise is valid. Testing of hypotheses derived from the proposition will ultimately reveal systematic exceptions to the relationships (Huber, 1990, pp. 53-54).

People: Effects on Participation in Decision Making

Proposition 1: Has the use of computer-assisted communication technologies led to a larger number and variety of people participating as information sources in the making of a decision?

Organizations have a tendency to utilize technologies that transfer messages in a timely and accurate manner. Additionally, however, the social acceptability of the technology (Fulk *et al.*, 1987), the ease of use (Huber, 1982), and other attributes (Culnan and Markus, 1987) are also important. This proposition indirectly addresses (a) the importance or significance of the increased participation; (b) the higher quality or better acceptance of the decisions made; (c) the existence of either "hard" information, "soft" information, or both; and (d) whether or not the decision process is made more effective because of the increase in number and variety of people involved. Johansen (1984, 1988) and Rice (1984) present reviews of the effects that computer-assisted communication technologies have on groups and group behaviors. Svenning and Ruchinskas (1984) present a summary of the behavioral effects of teleconferencing.

With the increasing adoption of various forms of advanced information technologies at the six architecture and engineering design firms, the opportunity for a larger number and variety of people can participate in the decision making process and can serve as additional information sources. This opportunity for including additional people in the process, however, is still predicated upon management approval or project need for their participation. The use of some forms of advanced information technologies permits increased participation by more personnel and of personnel with a more diverse design background. It was apparent at Firms A, C, D, E, and F, that the prevalence of AIT, particularly in the case of CAD and PC-based design applications, meant additional personnel could be included in design decisions. The rapid electronic transfer of large amounts of design information facilitates the inclusion of personnel that, previously, may have been excluded from decisions, just for the sake of reducing project time schedules. At Firm B, AIT is not yet available to a sufficient number of design personnel to support this proposition at that firm. However, the conclusion in support of this proposition would, in all likelihood, be the same for Firm B, as well.

People: Effects on Size and Heterogeneity of Decision Units

Proposition 2: Has the use of computer-assisted communication and decision-support technologies led to decreases in the number and variety of members comprising the traditional face-to-face decision unit?

Proposition 2 maintains that the number and variety of members meeting in traditional groups settings will decrease with the use of either computer-assisted communication or decision-support technologies. Lee, McCosh, and Migliarese (1988) and also Sabatier (1978), concluded that there is a tendency for individuals to select decision aids and techniques that facilitate timely and accurate decisions. Feldman and March (1981) and Sabatier (1978) recognize, however, that there are other important criteria in the selection of the technology to be used.

The use of computer-aided design systems has resulted in a decrease in the number and variety of architecture and engineering design personnel that formerly met in a face-to-face decision unit (Yetton *et al.*, 1993). The adoption of electronic mail, voice mail, personal computers, CAD, and even image transmission over computer networks, has reduced the need for the traditional project reviews of even just a decade ago. Architectural personnel at Firm B still meet, usually on a weekly basis, to conduct design reviews and to communicate project status to the other members of the project team. Parts of these meetings are for the express purpose of sharing information in a group setting. Management at Firm B feels that face-to-face design reviews are an inherent aspect of the art and that the adoption of AIT should not be permitted to displace this necessary form of communication among fellow architects. At Firm A, Firm C, Firm D, and Firm F, however, the use of local area networks has resulted in a reduction of the variety of personnel needed to accomplish design tasks. For example, typing of engineering specifications on word processors or personal computers by secretaries or technical clerks has generally been eliminated through the incorporation of these functions in computer-aided design software. Drafting personnel have been replaced by CAD designers on a large scale. Many of the engineer's responsibilities for design reviews and checks have been absorbed by the CAD designer and rule-checking capabilities that now exist in various CAD packages. The traditional role of an engineering project leader has been transformed to one of resource allocator, rather than that of design verifier. CAD designers and engineers have, over time, virtually eliminated the “pure” drafter function. Only in the case of architectural creativity at Firm B was there an obvious intent to maintain the traditional face-to-face meeting. Even at Firm B, however, the expectation of the technology manager is that some types of jobs could be shifted to the CAD base, particularly those dealing with the creation of physical models. Tradition is still strong for a dependence on physical models of architectural designs, however.

Task: Effects on Meetings

Proposition 3: Has the use of computer-assisted communication and decision support technologies resulted in less of the organization's time being absorbed by decision-making meetings?

Since computer-assisted communication technologies can facilitate participation by persons remote in either time or distance, more people may be involved in a decision than would otherwise be included (Kerr and Hiltz, 1982). Huber feels that validation of Proposition 3 would be important in terms of identifying the effect that computer-assisted technologies have on an organization's processes. It would be desirable, although unlikely, that individual technologies could be researched for their effects on decision meetings, since technologically advanced organizations may utilize several technologies. [Rice and Bair, 1984 discuss the costs and benefits of meetings supported by technology.]

There was empirical evidence at all six A&E design firms researched that the use of information technologies used in computer-assisted communications and decision support functions has resulted in less time being required for meetings. Proposition 3 is similar to Proposition 2, except that Proposition 3 deals with the organization's time. This may be a moot point, since in actuality the organization is composed of individuals. If there is a reduced need for both numbers and variety of people to produce a decision, as Proposition 2 maintains, then there would be a corresponding decrease in the total amount of labor time consumed within the organization. Therefore, Proposition 3 focuses on time in the organization and is an extension of Proposition 2.

As an example, the use of voice mail and electronic mail at all six A&E design firms has resulted in fewer meetings, and on a less frequent schedule, in order to disseminate information. At Firm B, however, meetings are still held in order to conduct the traditional project reviews meeting. The use of computer-aided design systems appears to have also contributed favorably to a dramatic reduction in the need for project review meetings at the other five firms as well.

Task: Effects on Centralization of Decision Making

Proposition 4: For a given organization, has the use of computer-assisted communication and decision-support technologies led to a more uniform distribution, across organizational levels, of the probability that a particular organizational level will make a particular decision?

Huber's intent with Proposition 4 is that a given organizational level will be more likely to be the one to make a particular decision, if computer-assisted communication and decision support technologies that use advanced information technologies are involved in the decision process. Research evidence for support of this proposition was not apparent at any of the six A&E design firms. In the instance of computer-aided design applications, however, there is a very high probability that a CAD designer or engineer will tend to make more decisions without resorting to conference with other designers or engineers, as discussed or implied in Propositions 1, 2, and 3. Therefore, support for this proposition could be contingent upon the specific advanced information technology being used by a particular organizational level. To this extent, then, Proposition 4 could be valid, since, designers and engineers are more likely to utilize CAD than do supervisory or managerial levels of an organization.

Huber proposes two corollary propositions that address the arguments relating to organizational centralization/decentralization due to the use of advanced information technologies.

> Proposition 4a: For a highly centralized organization, has the use of computer-assisted communication and decision-support technologies led to more decentralization?
>
> Proposition 4b: For a highly decentralized organization, has the use of computer-assisted communication and decision-support technologies led to more centralization?

Huber discusses the paradoxical dichotomy of Propositions 4a and 4b. Proposition 4a is believed to be true for highly centralized organization because advanced information technologies provide the opportunity for more decisions to be made by decentralized groups. Conversely, advanced information technologies would provide a highly decentralized organization the opportunity to further centralize its decision-making process. If viewed as a centralized-decentralized continuum, advanced information technologies present the opportunity to restrict decision-making to either a centralized group or to a decentralized group. Because of this paradoxical nature of advanced information technology, Huber feels that the likelihood is increased that a particular level of an organization will make the decision.

Propositions 4a and 4b represent an organizational structural continuum. As a concept, the use of advanced information technologies for communication and decision making activities results in a shifting of control depending upon the degree of centralization or decentralization for an organization. For example, a highly centralized organization would tend to make decisions in a central group. The use of AIT, however, would tend to distribute control of the decision through the rapid dissemination capabilities of computer-based information technologies. It could be argued that the use of security and access privileges to specific information could actually make control easier for a centralized organization. Conversely, the use of these same security and access privileges at a highly decentralized organization could result in maintaining the status quo by preventing access and sharing of the communications and decision making technologies.

Evidence to support Proposition 4a was observed and collected at Firm A, Firm C, Firm D, Firm E, and Firm F. These firms have relatively large investments in advanced information technologies, and through the increasing use of LAN and WAN computer networks, decentralization has occurred in the sense that the ability to act on information has resulted in less need for a decision at a central organization. The central organization, however, could limit access to architectural or engineering information, thereby reducing decentralization of the decision making process. This did not appear to be the case at the A&E design firms, however, since management had become comfortable with the concept of having lower levels of architects, designers, and engineers make technical decisions through the use of computer-aided design systems, in particular.

No evidence was found at any of the six A&E design firms for supporting Proposition 4b.

Structure: Effects at the Organizational Level

Proposition 5: For a population of organizations, has broadened use of computer-assisted communication and decision-support technologies led to a greater variation across organizations in the levels at which a particular type of decision is made?

Advanced information technologies do not inherently exclude different levels from being the decision-maker level in an organization. Huber feels, however, that the use of advanced information technologies increases the variation in the levels for a population of organizations for which a specific decision is made. Considerations such as political issues, organizational traditions, norms, culture, and preferred management style do not appear to preclude the use of advanced information technologies. However, some A&E design firms have an organizational structure that is flatter, with fewer levels than do other design firms. This appears to be particularly true for the smaller A&E design firms. The likelihood of a particular organizational level being the decision-making level appears to depend also on the size of the organization. Therefore, the causal implication of Proposition 5 appears to be tenuous, although the use of advanced information technologies may also contribute to the likelihood of a decision being made by a particular organizational level.

The research, however, focused on large A&E design firms, and so, this is a speculative observation by the author. Empirical evidence collected at the six A&E design firms researched did not appear to support Proposition 5. Whether this lack of support for the proposition is due to the small sample size, variation in organizational size, organizational structures, or decision making protocols at the six firms, or for other reasons, is unknown.

Structure: Effects on the Number of Organizational Levels Involved in Authorization

Proposition 6: Has the use of computer-assisted communication or decision-support technologies reduced the number of organizational levels involved in authorizing proposed organizational actions?

Shumway *et al.* (1975) found that as many as seven hierarchical levels were required for authorization of a research and development budget. Due to the time for each level to review and consider its judgments, the more time was required for the total process. Additionally, timeliness and enthusiasm were also adversely affected by the lengthy time duration. The question then arises concerning which organizational level is involved in a specific decision. Each level of an organization possesses knowledge or information unique to that level that qualifies it to apply criteria that lower levels cannot. Higher levels of an organization tend to possess more knowledge about organization-wide issues and needs than do lower levels. Therefore, the more information needed across multiple issues, the more likely that more and higher levels of the organization will be involved in a decision.

Huber proposes that with the increased use of advanced information technologies, fewer levels of an organization are needed for the same decision. This is particularly true since the appearance of such technologies as management information systems, expert systems, electronic mail, and on-line data bases.

There was empirical evidence found for support of Proposition 6 at four of the A&E design firms. Fewer management levels at Firm A, Firm C, Firm D, and Firm E are required for decisions relating to the acquisition and use of advanced information technologies for a given design project. One of the reasons given suggested that the falling prices of advanced information technologies had resulted in a redefinition of authorization and approval levels needed for acquiring these technologies. At Firm B, however, several management levels were required for approval of various advanced information technologies. It is believed that this requirement was based more on controlling financial expenditures than concern over standardization of hardware, software, or information data bases. Decisions at Firm F did not appear to be correlated with the existence or use of computer-assisted communication or decision support technologies. It is suggested that this might be due to the relatively limited integration of advanced information technologies within the information infrastructure at Firm F. Another explanation could be related to an organization's culture. Some organizations use advanced information technologies for design-oriented activities, yet do not rely upon these same technologies for aiding directly in reducing the number of levels of the organization. Again, this appears to be contingent upon factors other than just whether or not an organization uses computer-assisted communication or decision support technologies.

Structure: Effects on the Number of Nodes in the Information-Processing Network

Proposition 7: Has the use of computer-assisted information processing and communication technologies led to fewer intermediate human nodes within the organizational information-processing network?

Proposition 7a: Has the use of computer-assisted information processing and communication technologies reduced the number of organizational levels involved in processing messages?

Most organizations require sensor functions to collect data and information either internal or external to the firm. This information is then typically passed on to other, higher levels in the organization. This requires additional time and costs for processing and relaying information to the appropriate decision-making units. Many organizations have adopted advanced information technologies in an attempt to reduce these time delays and additional costs.

Proposition 7a is similar to Proposition 4, except that Proposition 7a focuses on the decrease in the number of organizational levels involved in processing messages, whereas Proposition 4 focuses on the likelihood or probability that a specific organizational level will make a decision due to the use of computer-assisted communication technologies. The distinction between Proposition 4 and Proposition 7a is subtle, yet important. The use of computer-based information technologies or AIT at most of the six firms appears to have resulted in a reduction of the number of organizational levels necessary to affect a decision. This leads, in turn, to an increase in the probability or likelihood that a specific organizational level will then be the one to make a given decision. Therefore, Proposition 4 and Proposition 7a are related propositions dealing with organizational structure.

Technology: Effects on Organizational Memory

Proposition 8: Has the availability of computer-based activity and transaction-monitoring technologies led to more frequent development and use of computer-resident data bases as components of organizational memories?

Although certain persons within an organization serve as components of the organization's memory, advanced information technologies are being utilized more extensively to provide ready access to corporate data. With reductions in the numbers of employees, additional motivation exists to transfer memory functions to computer-based systems, especially when combined with organizational rules of processes, procedures, and rule-based policies.

There was empirical evidence at five of the A&E design firms to support Proposition 8 in the affirmative. Firm B did not appear to investing any major financial and personnel resources into the development of computer-based information data bases. The reasons for this appear to be limited capital for investment in advanced information technologies, insufficient numbers of personnel skilled in developing and utilizing data bases supported by various AITs, and an overall scarcity of these technologies. Apparently, Firm B is still in an early stage of adoption of AITs and this might account for the limited use of computer-based information sources.

Evidence at Firms A, C, D, and E indicates that these firms are aggressively pursuing the development of various computer-based information data bases. Firm F is pursuing offthe-shelf products for developing data bases, but management there recognized their limitations in terms of in-house development. Therefore, based upon empirical evidence at five A&E design firms, Proposition 8 seems to be supported.

Proposition 9: Has the availability of more robust and user-friendly procedures for constructing expert systems led to more frequent development and use of in-house expert systems as components of organizational memories?

The increased utilization of advanced information technologies has led to more widespread use of in-house experts to aid in both further development of these technologies and as effective users of these technologies. The optimal utilization of computer-aided design technologies, for example, requires that rules and procedures be embedded as part of the engineering design protocol. Design, review, and approval cycles have been incorporated into CAD systems and knowledge of these functions is derived from the organization's own experts.

Huber (p. 61) maintains that Propositions 8 and 9 imply that specific advanced information technologies serve to increase the range of an organization's memory components and can be contrasted with other AIT forms that increase the range of media formats that can be used to communicate the organization's information and knowledge.

There was strong empirical, although anecdotal, evidence at all six A&E design firms that the use of advanced information technologies has required the additional use of experts as part of the corporate memory. Although Huber uses the phrase "in-house expert systems," it is clear that he is discussing both human experts and expert systems as part of the corporate memory. Management at all six firms recognized their dependence on computer experts and project leaders to successfully administer the use of AIT for design work. In some instances, anecdotal evidence suggests that the use of human experts supersedes the use of database or other information sources for identifying and retrieving information that has been previously completed and archived in magnetic form. Part of the reason for the use of human experts as an extension of corporate memory appears to be the ease with which index keys about the desired information can be obtained by verbal or written request. Human experts are often able to describe a project in terms that data bases do not, and, therefore, they become part of the corporate memory for use by project leaders and other management.

Information: Effects on Organizational Intelligence and Decision Making

Proposition 10: Has the use of computer-assisted information processing and communication technologies led to more rapid and more accurate identification of problems and opportunities?

Most organizations conduct scanning of their external and internal environments for information relating to problems and opportunities. In some instances, inherent delays occur as information is passed through the organization's communication network. In other cases, the organization's members experience difficulty linking to other members in an appropriate time to transfer information expeditiously. Therefore, the use of computer-assisted information processing technologies aid to the more accurate and timely dispersion of information throughout the organization.

As one example, Firm F uses commercial satellite feed for marketing and sales personnel to monitor information about proposed governmental and industrial projects that may become potential projects for the firm. In some instances, use of on-line information services has given Firm F a definite edge over its competitors in terms of environmental scanning. Frequently, the time to respond to proposals for bids on large projects is limited by the prospective customer, who wants to have a rapid decision regarding project pricing. Firm F has gained several days over its competition by being aware of upcoming project work and therefore, being able to allocate engineering resources to developing a response to a project proposal prior to the actual receipt of a formal, written Request for Proposal. This permits Firm F to deliver a more accurate and cost-effective proposal that results both in a greater likelihood of being awarded the project and in the likelihood of being able to deliver the project at the specified time and cost.

Proposition 11: Has the use of computer-assisted information storage and acquisition technologies led to organizational intelligence that is more accurate, comprehensive, timely, and available?

This proposition is predicated upon the assumption that an organization's external information sources are accurate, comprehensive, timely, and available. However, the statement implies that the use of advanced technologies for information will result in increased organizational intelligence.

Empirical evidence for support of Proposition 11 was inconclusive for the six A&E design firms researched. Management and technical personnel at all six firms believe that the use of CAD, digital scanning devices, and disk storage technologies, like RAID, has resulted in improvements for access to the organization's information. Not in all cases or applications of advanced information technologies, however, have access and retrievability been improved from a total corporate perspective. Depending upon the organization's ability to define information workflows and to acquire and implement advanced information technologies that serve to improve the workflow process, has there been a commensurate improvement in organizational intelligence. Hammer (1990), for example, makes a compelling argument that information automation must be preceded by a reengineering of the organization. Other researchers have also subscribed to this view of automation in general, and the automation of information in particular (Kouloupolos, 1994).

At Firm A, Firm C, Firm D, and Firm E, corporate engineering project indices are used for retrieval of useful engineering design information and in magnetic form. The management at these firms were aware of the problems inherent in reconstructing project designs and related engineering information by depending upon the memory recall of technical personnel. These firms have implemented project closing reviews for engineering projects that include personnel representation from the computer-aided engineering organizations. This serves to ensure that all electronic information is properly archived so that the information can be readily retrieved and restored at a later time. This project protocol has permitted these firms, according to both management and technical personnel, to reestablish engineering designs in a reasonable amount of time. The ability to accomplish this has become a key strategic advantage for these A&E design firms for obtaining repeat projects from the came customers.

In contrast, at Firm F, although CAD is being used for producing large quantities of geographical drawings and database information, archiving of project files is accomplished by storing all documents and media, including magnetic disks, in boxes for off-site storage. Retrieval of the information related to a specific project can occur relatively easily and rapidly. Restoration of the information in the proper form on various advanced information technology platforms, however, is still cumbersome and time-consuming. Software versions of CAD applications packages change over time, tending to present operational problems long after successful completion of a design project.

Information: Effects on Decision Making and Decision Authorization

Proposition 12: Has the use of computer-assisted communication and decision-support technologies led to higher quality decisions?

The presumption of proposition 12 is that the quality of decisions should be improved in organizations that effectively utilize the communications capabilities of various forms of advanced information technologies. By facilitating the sharing of information among decision-making units, higher quality decisions can be obtained. Combined with computer-assisted decision-aided technologies, the quality of decision making is also improved.

Both management and technical personnel at all six A&E design firms expressed their conviction that the use of computer-assisted communication and decision-support technologies had resulted in higher quality decisions for both business and technical reasons. Since the use of advanced information technologies has resulted in additional slack time compared to the use of traditional technologies, this time could now be applied to further improvements in the architectural or engineering design of projects.

Firm A is utilizing the additional time extracted from engineering design schedules to perform additional design scenarios for the customer, typically at the same cost. The quality of final designs has thereby been improved. Management at Firms B, C, D, E, and F also reported that the use of these technologies had resulted in slack time that can either be reinvested in additional design concepts, simulations, or scenarios.

Proposition 13: Has the use of computer-assisted communication and decision-support technologies reduced the time required to authorize proposed organizational actions?

By reducing the number of levels involved in authorizing a decision or action, a corresponding reduction occurs in the number of times a decision proposal must be handled within an organization. Huber laments the lack of systematic research in this area, particularly the lack of understanding about the effects of AIT on authorization as a specific requirement in the decision-making process.

Empirical evidence at all of the six A&E design firms tended to support Proposition 13. Numerous instances and examples of the reduction in time to authorized organizational actions were provided by management, architects, engineers, and designers that were interviewed. There appears to be almost universal belief by these personnel that the use of advance information technologies has contributed substantially to a reduction in the amount of time needed to make a decision that requires organizational resources. As discussed previously, many of the design decisions formerly made by engineers are now being accomplished routinely by designers that have CAD skills. With rule-based CAD standards, there is less time needed to accomplish the same task.

The use of voice mail and electronic mail has also contributed positively to a reduction in the amount of time needed to obtain a decision. Formerly, the involvement of multiple personnel generally was required to either serve as an intermediate message-handling function prior to the adoption of voice mail or to produce a written document in the case of electronic mail.

These functions are now typically accomplished by the originator of the message through the use of advanced information technologies, which has resulted in less time for the organization as a whole to authorize a given organizational action.

Proposition 14: Has the use of computer-assisted communication and decision-support technologies reduced the time required to make decisions?

Huber believes that available evidence supports Proposition 14, although he suggests that studies using casual self-reported instances of time reductions in decision-making due to the use of advanced information technologies need to be supplemented with systematic research like those reported by Rice and Bair (1984).

The overwhelming consensus of managerial and technical personnel at all six A&E design firms was that the use of computer-assisted communication and decision-support technologies does result in less time required to make decisions. In the case of computer-aided design, however, the time saved through the use of the tool is typically spent on considering other design alternatives. Although the amount of time required for a given design decision has been reduced by the use of advanced information technologies, the time "saved" is reinvested in considering additional architectural or engineering designs. The presumption by management and technical personnel at all six A&E design firms was that utilizing the time saved through the use of advanced information technologies resulted in a much higher quality service that resulted in superior engineering designs for their customers or clients.

Chapter Summary

Chapter 6 presented Huber's theory of the effects of advanced information technologies on organizations. A summary of each of Huber's fourteen propositions was presented in order to provide a framework for presenting some of the findings from the field research conducted at the six A&E design firms. In most instances, empirical data collected tended to support Huber's propositions, although research evidence for several of the propositions was weak or indeterminate. Chapter 7 presents a summary of the research and the conclusions drawn for the impact of advanced information technologies on the six A&E design firms examined.

CHAPTER 7

RESEARCH CONCLUSIONS

Chapter Objective

The objective of Chapter 7 is to discuss the conclusions related to the research about the impact of advanced information technologies on the A&E design firms examined. Future research issues for several areas are also presented.

Research Summary

The objective of the research was to determine the impacts that advanced information technologies have had on A&E design firms and to determine if these impacts have been favorable. The research model included the use of a questionnaire developed through use of an expert Delphi panel. The research also included a conceptual model developed as a synthesis of Leavitt's four components of organizations and Huber's theory of the effects of advanced information technologies. The field research findings were analyzed in terms of Huber's fourteen propositions dealing with the effects of advanced information technologies on organizational design, intelligence, and decision making.

The basic question for the dissertation research was stated as:

> What has been the impact of advanced information technologies on architecture and engineering design firms, and to what degree have competent architecture and engineering firms implemented advanced information technologies into their design services?

The field research focused on identifying the distinctive characteristics that competent architecture and engineering design firms possess or exhibit in the utilization of advanced information technologies in terms of a competency indicators instrument.

As was seen through the interviews with managers, architects, engineers, and designers, the impact on the six A&E design firms has been pervasive and has affected all of the major components of these organizations identified in the conceptual research model; namely, structure/strategy, personnel, technology, task, and information. The implementation of advanced information technologies into A&E design work processes ranges from drawing creation to archiving, from specifications searching to specifications published, and from project initiation to project closing. There was variation among the six firms researched in terms of the pervasiveness of AIT, but some of this is due to the differences in sizes and financial ability of the design firm. In all cases, management was aware of the urgency and need to transform its respective A&E design firm into an information gatherer and processor. Its greatest concerns were over the difficulty of retrieving information in a timely manner and in the proper form once archived and the integration of AIT with work processes inside the firm. Management was, in general, comfortable with the notion of the information engineer and with the ability of their personnel to adapt to even further changes in the work environment brought about by the continuing advance of advanced information technologies.

Research Conclusions

The research findings appear to support most of Huber's propositions regarding the effect of advanced information technologies on organizational design, intelligence, and decision making as presented in Chapter 6, where the exceptions were discussed also. Considering the research findings, there appears to be support for Huber's premise that the availability and use of advanced information technologies leads to improvements in the effectiveness of organizational design, intelligence, and decision making. Anecdotal evidence from managers, architects, engineers, and designers was consistent among all six A&E design firms regarding the positive benefits from the use of advanced information technologies in terms of improving organizational intelligence and decision making.

Although most, if not all of the empirical data collected and summarized is subject to criticism from a positivist view, there is a preponderance of anecdotal and descriptive evidence to show that the impacts of advanced information technologies on architecture and engineering design firms has been mostly favorable. The difficulty lies in ascribing precision to the empirical evidences for this. As Sutherland has stated so eloquently, "not all real-world phenomena will ultimately become deterministic if we spend enough time analyzing them" (1973, p. 145).

Organizational strategy and structure have been changed both to accommodate these technologies and, at the same time, to exploit their benefits. Although an argument could be made for rejecting *a posteriori* evidence, the continuing adoption of various forms of advanced information technologies provides strong evidence that the benefits and limitations are being rationalized by management of large A&E design firms. Otherwise, the continual acquisition process would have devolved and a reluctance to acquire these technologies would have become the norm.

Changes affecting personnel involved in the acquisition, implementation, development, and utilization of advanced information technologies has also had an important impact. Career positions now exist for managers, engineers, architects, and designers involved in implementation and development of advanced information technologies, which a decade or so ago were nonexistent. In many cases, technical personnel from the architecture and engineering ranks fill positions that would have been staffed from management information system groups. Due to the need for these application developers to possess an intimate knowledge and understanding of the use of the information in the discipline, staffing these new functions with MIS personnel has not been feasible. Training programs have been implemented and supported in order to develop the personnel component of the organizations using these technologies.

A common characteristic observed at all of the six A&E design firms was that of technology "champion" or other personnel chartered to assume this role. In most cases, it was apparent that one of the reasons for the strong commitment to the adoption of AIT could be attributed to individuals who saw the benefits of advanced information technologies even whenever others in the firm did not. A substantial body of research supports the need for such a role or function if an organization is to successfully acquire and develop information technologies (Schon, 1963; Roberts, 1968; Tushman and Scanlan, 1971; Zaltman, 1973; Maidique, 1980; Kanter, 1983; Vitale *et al.*, 1986; Pennings and Buitendam, 1987; Beath and Ives, 1988; Howell and Higgins, 1990; Reich and Benbasat, 1990; Beath, 1991; Ciborra, 1991).

In the Pulitzer prize-winning book, The Soul of a New Machine, Tracy Kidder (1981) provided a view into the obstacles faced by the leaders of a small development group of a new line of computers at Data General Corporation. Although the setting is in a different industry than that of A&E design firms, the message appears clear that novel and risky innovations require the support of one or more visionaries who are willing to sacrifice career conservatism for the opportunity to achieve goals for the organization's overall good. These visionaries or entrepreneurs are typically viewed as mavericks and often have goals that are divergent from those of the organization. This appears to be a similar phenomenon that was encountered and reported at the six A&E design firms.

With respect to organizational strategies related to information technology, Yetton *et al.* (1993) present a case study in an architectural firm that demonstrates that acquisition and development of information technologies does not always follow the traditional business strategy paradigm (Chandler, 1962; Rumelt, 1974; Burgelman, 1983; Donaldson, 1987; Henderson and Venkatraman, 1992). Other researchers are also presenting evidence that the traditional views of the utilization of information technologies are short-sighted (McFarlan, 1981; Markus and Robey, 1988; Zuboff, 1988; Davenport and Short, 1990; Scott Morton, 1991; Davidow and Malone, 1992).

Design information for architecture and engineering design is being created, transmitted, and archived using advanced information technologies in ways not foreseen by early information systems developers and administrators. Standards relating to formatting and storage of information are still in a state of flux and this has contributed to the difficulty of easy transfer of design information from system to system, from group to group, and from firm to firm.

The range of advanced information technologies in use at some of the A&E design firms exhibits a tendency of technical personnel to "explore" technology options. Not in all cases did there appear to be technology acquisitions based upon rationalized technology plans. In some cases, this tendency to explore various aspects of advanced information technologies has yielded unexpected benefits, however. In other instances, initial investigations, followed by acquisition, have resulted in legacy systems that have been counterproductive to other information technology plans and needs. The inferences drawn from anecdotal evidence seem to support that some exploration is necessary if the benefits of

AIT are to be "discovered." On the other hand, acquisition of AIT without a rational planning base tends to result in fragmentation of resources. The on-going costs to the firm continue to increase once a specific advanced information technology has been acquired and later becomes a counteracting legacy system, one that is information-incompatible with respect to other advanced information technologies.

Regarding decision making as a primarily managerial activity, however, Keen (1981) observed: "The point is not that managers are stupid or information systems irrelevant but that decision making is multifaceted, emotive, conservative, and only partially cognitive." He goes on to cite evidence about the social inertia that occurs in organizations that results in resistance and counterproductive implementations of information systems. Complex decision making using quantified information appears to be a relatively minor aspect of the process (Pettigrew, 1973; Bower, 1970). Rules of thumb, habit, discussions, and the "muddling through" process (Lindblom, 1959) appear to have more significance than rational analysis of empirical or quantified data.

The changes in task or activity requirements for conducting architecture and engineering design brought about by advanced information technologies can be described as revolutionary. As seen through the field research, the tools formerly used by architects and engineers have been displaced almost entirely by the advent of advanced information technologies. Although there is still a small population of traditional designers and drafting personnel, this function is nearly extinct in the engineering design profession. The architectural profession still relies on traditional graphical art approaches for developing concepts, but even here the use of digital imaging and computer-aided design systems is displacing this function to some degree as well. The concept of CAPE, or Concurrent Art-to-Product, is beginning to be adopted by some of the A&E design firms researched.

Another relatively new AIT development is that of groupware applications in which a design activity or task can be allocated to multiple users simultaneously. In this case, parallel activities can be accomplished by multiple personnel, even though their individual tasks are different. CAD conferencing with file sharing capabilities is an example that has already demonstrated its benefits for reducing travel costs and shortening project schedules.

The information component of organizations has become largely computer based. Information is now both more voluminous and available in more types of media and information formats than prior to the advent of computer-based design applications. This has produced mixed blessings for A&E design firms. Design information can be created, transmitted, and stored at electronic speeds, but the lack of and adherence to proper information archive and retrieval procedures often results in sub optimal reuse of design information, largely due to the difficulty of relocating, retrieving, and restoring this information from project archives.

Those A&E design firms that have a proactive program of information technology appear to have a better strategic advantage than those firms that acquire and utilize advanced information technologies on an ad hoc project basis. Development of corporate indices for rapid retrievals of architecture and engineering information seems to be a universal need for A&E design firms. Commensurate with this, a reengineering of the firm in terms of delivering the best value to the firm's clients is warranted. Too many legacy systems, a general lack of information standards and protocols for dissemination of information, and a lack of concern for long-term technology programs are all contributing to the suboptimal use of advanced information technologies.

The practice of architectural and engineering design is now intimately tied to the use of advanced information technologies. Although paper and related media will continue to be used as the method of manual distribution, the decided preference for initial creation and dissemination of design information is now being accomplished through the prevalent use and commitment to various advanced information technologies.

In their book, The Virtual Corporation, Davidow and Malone (1992) discuss business as information. At the end of the twentieth century, the use of computer-based information technologies has resulted in a very small percentage of employees in the modern industrial firm actually being involved in the production process -- perhaps a few as five percent. The majority of the remaining employees are involved in processing or transforming information. They discuss the productivity dilemma of computers and information. Robert Solow, a Nobel laureate, said: “We see computers everywhere but in the productivity statistics” (1991). Michael Borrus provides part of the answer concerning the lack of supportable, empirical evidence for the tens of billions of dollars on computer equipment in the United States. Borrus suggests that the incorporation of new technologies into the old methods of doing business can explain why the use of computers and increasing productivity have not been justified by the data available (Davidow and Malone, p. 66). Therefore, the inconclusive evidence that is available suggests that the real impact of computers is yet to occur and that real productivity gains will be manifested in the “virtual corporation” as defined by Davidow and Malone (1992, p. 67). As an analogue, Paul David of the Center for Economic Policy Research at Stanford found a similar lag between the introduction of electricity and a change in the productivity data. He says: “In 1900 contemporaries might well have said that the electric dynamos were to be seen ‘everywhere but in the economic statistics.’” (Davidow and Malone, p. 67).

As a general premise, Ellul (1964) and Winner (1977) maintain that technology results in social changes that go far beyond the original application. A self-sustaining evolutionary path occurs. Winner uses the example of electrical power plants for producing electricity that resulted in institutionalizing various other technologies for which they were originally intended to support. Therefore, technology in general carries its own seeds of further development and in ways not foreseen originally (Markus and Robey, 1988).

The issue of abandoned technologies, then, appears to be predicated upon whether an infrastructure to support the technology occurs or not. If development of a supporting infrastructure does not occur, then the technology does not mature or may even expire. Similarly, the reason for the continuing adoption of various advanced information technologies in A&E design firms appears to be occurring because the information itself requires more and more computer-based platforms in order to avoid data transfer obstacles.

As a conclusion, then, the impact of advanced information technologies on architecture and engineering design firms appears to have been substantial and pervasive, affecting nearly the entire range of design activities in the firms researched. Information has become a strategic asset for A&E design firms that have been able to acquire the proper mix of strategy, structure, technology and personnel in order to utilize information effectively. The A&E design firms that appear to be the most competent in the use of advanced information technologies are those which have been able to remove or reduce the internal barriers so that design information is readily accessible and usable by managers, architects, engineers, and designers. Information as a distinct component or entity of the organization appears to be justifiable from the empirical data gathered.

Usefulness of the Research

The research conducted provides a model for practitioners and managers of A&E design firms that can be used for assessing competency in the use of advanced information technologies. The competency indicators list can also be used by prospective clients desiring to gauge the relative competency of A&E design firms in order to make a rational decision relating to the competent use of AIT.

The research model provides a systematic method that can be replicated for use by other researchers. Adoption of the Delphi technique and a panel of experts provides a useful tool for developing additional questions that will undoubtedly change as advanced information technologies and their applications also change.

Areas for Further Research

One of the important areas of advanced information technologies that needs further research is that of corporate access to architecture and engineering design information. Management at all of the firms researched expressed its concern and desire to be able to index, search, and retrieve summary information relating to completed projects as well as active projects. As personnel turnover occurs, it becomes increasingly more difficult for project leaders and others to derive value from advanced information technologies by capitalizing on designs previously completed on other projects. In the virtual A&E design firm, access to electronic information will be the norm. Competitive advantage will not be determined by whether or not a firm has access to specific design information, but rather whether it can access needed information more rapidly and more accurately than its competitors.

Unless indexes to corporate architectural and engineering design information are developed, organizations will not be utilizing the strengths of advanced information technologies to their fullest. Dependence on recall by personnel will continue to be the mechanism by which the existence of information is known about and recoverable.

The external environment of the A&E design industry needs further exploration in order to determine the type of impacts that have occurred since the introduction of advanced information technologies. Important legal issues and problems concerning the ownership of information have arisen for which current domestic and international laws do not resolve. Transfer of electronic data over networks across international borders presents special ownership and security issues that need to be better defined and examined in the industry. By transmitting data over electronic networks, the ownership of data becomes a critical legal issue, since once it has been "captured" by another corporate entity, the original ownership becomes difficult, if not impossible, to establish.

Chapter Summary

Chapter 7 provided a summary of the impacts of advanced information technologies on the A&E design firms researched. Conclusions related to the research findings were also presented to indicate some of the issues facing large A&E design firms, with suggestions for further research.

APPENDICES

APPENDIX A.

EXPERT ADVISORY PANEL

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Richard N. Stover, Publisher; *Document Management and Windows Imaging*, Scottsdale, Arizona.

Eric D. Teicholz, President; Graphic Systems, Inc., Cambridge, Massachusetts.

APPENDIX B.

PROFILES OF ARCHITECTURE & ENGINEERING DESIGN FIRMS

FIRM A

Firm A is one of the largest global engineering and construction companies with approximately twenty thousand employees. Firm A has major engineering offices in more than 30 countries and provides engineering design and construction services worldwide. The firm specializes in a large number of engineering projects and disciplines, including power generation; petrochemicals and refineries; civil engineering for transportation, buildings, and infrastructure; mining; aerospace and defense projects; manufacturing; and information technology. Annual revenues for 1993 were reported as more than $500 million.

FIRM B

Firm B is a moderate-sized architectural design firm with approximately one thousand employees involved in conceptual design and project management for large commercial buildings. Firm B employs approximately two hundred employees, with an emphasis on architectural design. The firm has received numerous domestic and international awards for its innovative and distinctive architectural designs. Annual revenues for 1993 were greater than $30 million.

FIRM C

Firm C is a large engineering design firm and offers engineering design services in more than 75 countries. Firm C has approximately ten thousand employees. The range of services offered includes planning, architectural design, engineering, and construction. The areas of concentration include petrochemical, pharmaceuticals, chemicals and related products, food and beverage, batch and process manufacturing, and extensive design services in civil construction projects for both the public and governmental sectors. Annual revenues in 1993 were reported as greater than $100 million.

FIRM D

Firm D is one of the largest engineering and construction firms in the U.S. and has engineering offices in more than thirty countries. Firm D employs approximately twenty thousand employees. Firm D specializes in providing engineering design and construction services in the following areas: process manufacturing, power generation, and industrial manufacturing. Annual revenues in 1993 were reported as being greater than $500 million.

FIRM E

Firm E is a moderate-size engineering firm with offices in approximately ten eastern U.S. states. Firm E employs more than two thousand engineering personnel. Firm E offers a wide array of engineering design services, including project management. The firm specializes in utilizing state-of-the-art technologies for process manufacturing, power generation plants, research and development centers, and commercial facilities. Annual revenues in 1993 were reported in excess of $100 million.

FIRM F

Firm F is a moderate-size architecture and engineering firm with several offices in the eastern United States. Firm F employs approximately two thousand engineering personnel for providing design services in the following areas: commercial and private office buildings; manufacturing facilities; transportation and facilities construction for local, state, and federal agencies; and land use and surveying. Annual revenues for 1993 were more than $50 million.

APPENDIX C.

TRADITIONAL ENGINEERING TOOLS AND INFORMATION METHODS FOR ARCHITECTURE AND ENGINEERING DESIGN FIRMS

Manual and Electric Typewriters
Engineering Drawing Paper:
- **Vellum**
- **Mylar**
- **Bond**
- **Diazo Paper**

Engineering Drawings
Drawing Number Logbooks
Drafting Boards and Instruments
Drafting Pens and Pencils
Drawing Erasers
Lettering Templates
Symbol Templates
Inking Equipment
Geometric Templates
Specifications
Parts Lists (Bills of Materials)
Reference Manuals
Aperture Cards
Microfiche
Plastic, Metal, or Wood Models
Photographs
Electronic Calculators
Slide Rules
Nomographs
Specification Tables and Schedules
Telephones
Meetings
Conferences

APPENDIX D.

ADVANCED INFORMATION TECHNOLOGIES CURRENTLY UTILIZED IN ARCHITECTURE AND ENGINEERING DESIGN FIRMS

CAD graphics systems:

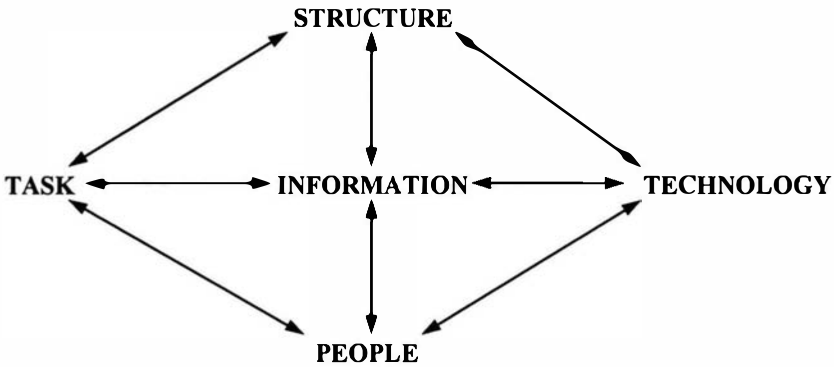
- 2D graphics
- 3D graphics
- Virtual reality graphics
- Data base software
- Digital models
- Solids modeling
- Finite element analysis
- Structural simulations
- Model animations

Facsimile (FAX) machines
Word processors
RAID storage devices
Engineering workstations
Personal computers
Client-server systems
Mainframe computers
Networks: LANs, WANs, and wireless WAN's
EDI for engineering products
Electronic documents management systems
Scanning and image processing equipment
Modems
Pen plotters
Color plotters
Color printers
Laser Printers
Optical character recognition
Intelligent character recognition
Smart raster-to-vector conversion
Computer Output Microfilm (COM) Printers
Computer Input Microfilm (CIM) Scanners
Electronic mail
Voice mail
Speech recognition equipment
Handwriting recognition equipment
Electronic conferencing

Data Bases: Hierarchical; Relational; Object-Oriented

APPENDIX E.

DISSERTATION RESEARCH MODEL



APPENDIX F.

MAPPING OF LEAVITT'S ORGANIZATION MODEL, HUBER'S PROPOSITIONS OF ADVANCED INFORMATION TECHNOLOGIES, AND 'INFORMATION'

	CONCEPTUAL MODEL OF AN ORGANIZATION				
	LEAVITT'S ORGANIZATION MODEL				
HUBER'S PROPOSITIONS	STRUCTURE	TECHNOLOGY	PEOPLE	TASK	INFORMATION
1			X		
2			X		
3				X	
4				X	
5	X				
6	X				
7	X				
8		X			
9		X			
10					X
11					X
12					X
13					X
14					X

APPENDIX G.

RESEARCH MODEL QUESTIONNAIRE

A. Organizational Strategy/Structure

1. What have been the objectives of leading A&E design firms in acquiring and implementing advanced information technologies?

2. Do advanced information technologies favorably impact the "success" or "competency" of A&E design firms?

3. To what degree does the use of advanced information technology impact the achievement of productivity and quality objectives?

4. Is there a minimum set of factors that must be present for A&E design firms to be effective in the use of advanced information technologies? What are these factors?

5. What are the indications or evidence for "successful" implementation of advanced information technologies?

6. What are the indications or evidence for "successful" utilization of advanced information technologies?

7. Are there identifiable similarities or differences among leading A&E design firms in terms of organizational strategy with respect to advanced information technologies?

8. In what ways have leading A&E design firms used advanced information technologies to enhance or strengthen their competitive position?

9. What impact have advanced information technologies utilized by leading A&E design firms had on their customers?

10. What are the organizational obstacles and problems encountered by leading A&E design firms in the acquisition and implementation of advanced information technologies?

11. What organizational problems will leading A&E design firms encounter in the future relevant to the acquisition, implementation, integration, and effective utilization of advanced information technologies?

12. Have there been changes in the organizational structure of leading A&E design firms as a result of advanced information technologies?

B. Technology

1. What advanced information technologies are now being used by leading A&E design firms in the engineering design process?

2. Are there identifiable similarities or differences among the leading A&E design firms in the manner in which they have integrated advanced information technologies?

3. What have been the benefits of advanced information technologies for leading A&E design firms?

4. Do leading A&E design firms monitor the improvements in productivity for their engineering services?

5. How well have leading A&E design firms managed the rapid changes in advanced information technology?

6. What are the characteristics of leading A&E design firms that have managed well the rapid changes in advanced information technology?

C. People

1. How have the work processes of architects, engineers, and designers been affected by the introduction of advanced information technologies into engineering design functions of leading A&E design firms?

2. How have architects, engineers, and designers influenced the acquisition and use of advanced information technologies in leading A&E design firms?

3. How do leading A&E design firms resolve personnel issues associated with the introduction of advanced information technologies?

4. What changes have occurred to management functions in leading A&E design firms due to the acquisition and implementation of advanced information technologies?

D. Task

1. Are there identifiable similarities or differences among the leading A&E design firms in the manner in which they have integrated advanced information technologies into their work processes?

2. How did the use of advanced information technologies affect traditional architectural and engineering analysis, design, and documentation tasks?

3. How has the use of advanced information technology affected the skills required by the individual architect or engineer?

E. Information

1. What changes have occurred within leading A&E design firms due to the availability of information resulting from the use of advanced information technologies?

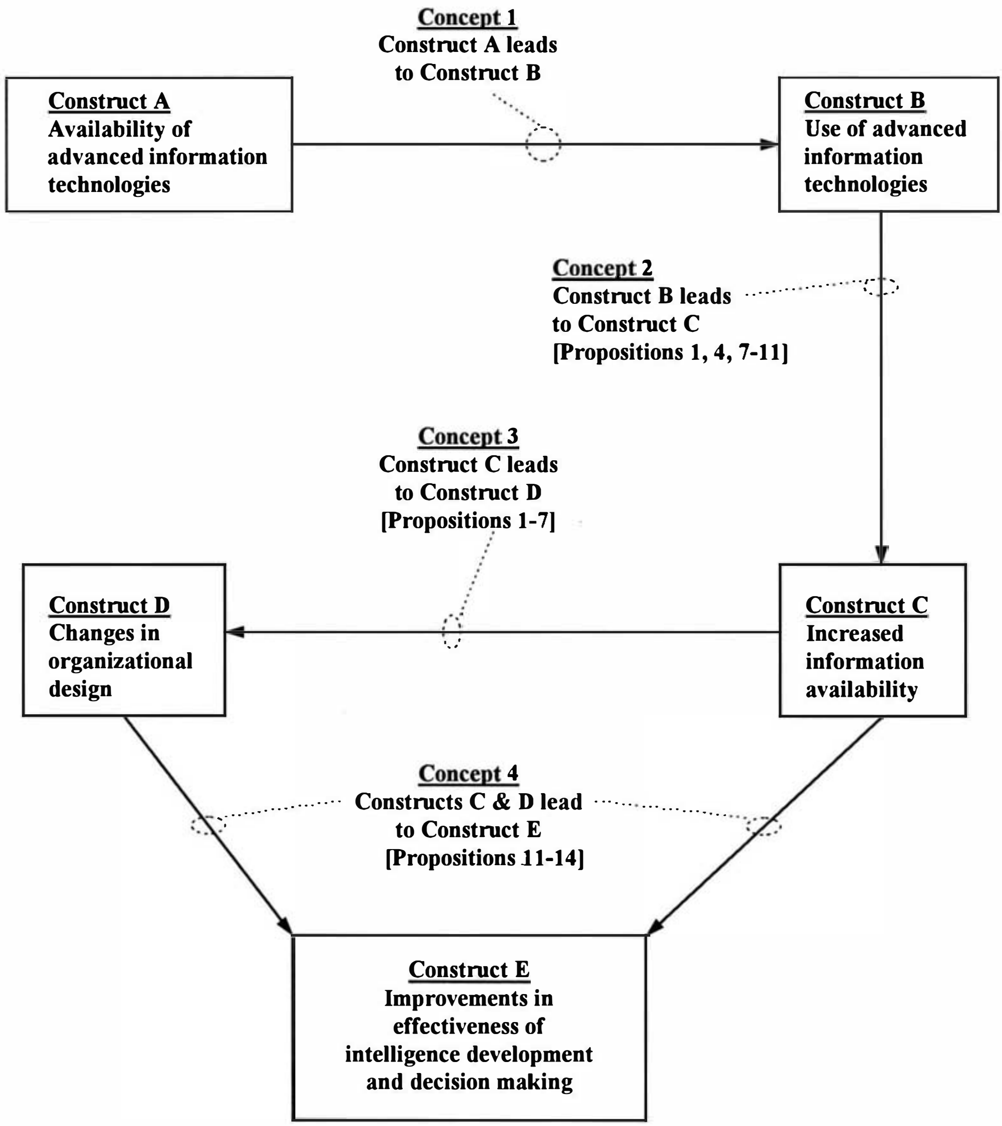
2. Has the use of advanced information technologies by leading A&E design firms affected the method of handling "as-built" information?

3. Are there evidences of "success" among leading A&E design firms due to the increased availability of electronic information?

4. How are information data bases currently being used by leading A&E design firms?

APPENDIX H.

HUBER'S MODEL OF THE EFFECTS OF ADVANCED INFORMATION TECHNOLOGIES ON ORGANIZATIONAL DESIGN, INTELLIGENCE, AND DECISION MAKING



Reference: George P. Huber, "A Theory of the Effects of Advanced Information Technologies on Organizational Design, Intelligence, and Decision Making," Academy of Management Review, 1990, Vol. 15, No. 1, Figure 1, p. 66. [Propositions added by the author.]

APPENDIX I.

HUBER'S PROPOSITIONS FOR THE THEORY OF THE EFFECTS OF ADVANCED INFORMATION TECHNOLOGIES ON ORGANIZATIONAL DESIGN, INTELLIGENCE, AND DECISION MAKING

Proposition 1: Use of computer-assisted communication technologies leads to a larger number and variety of people participating as information sources in the making of a decision.

Proposition 2: Use of computer-assisted communication and decision-support technologies leads to decreases in the number and variety of members comprising the traditional face-to-face decision unit.

Proposition 3: Use of computer-assisted communication and decision support technologies results in less of the organization's time being absorbed by decision-making meetings.

Proposition 4: For a given organization, use of computer-assisted communication and decision-support technologies leads to a more uniform distribution, across organizational levels, of the probability that a particular organizational level will make a particular decision.

Proposition 4a: For a highly centralized organization, use of computer-assisted communication and decision-support technologies leads to more decentralization.

Proposition 4b: For a highly decentralized organization, use of computer-assisted communication and decision-support technologies leads to more centralization.

Proposition 5: For a population of organizations, broadened use of computer-assisted communication and decision-support technologies leads to a greater variation across organizations in the levels at which a particular type of decision is made.

Proposition 6: Use of computer-assisted communication or decision-support technologies reduces the number of organizational levels involved in authorizing proposed organizational actions.

Proposition 7: Use of computer-assisted information processing and communication technologies leads to fewer intermediate human nodes within the organizational information-processing network.

Proposition 7a: Use of computer-assisted information processing and communication technologies reduces the number of organizational levels involved in processing messages.

Proposition 8: Availability of computer-based activity and transaction-monitoring technologies leads to more frequent development and use of computer-resident data bases as components of organizational memories.

Proposition 9: Availability of more robust and user-friendly procedures for constructing expert systems leads to more frequent development and use of in-house expert systems as components of organizational memories.

Proposition 10: Use of computer-assisted information processing and communication technologies leads to more rapid and more accurate identification of problems and opportunities.

Proposition 11: Use of computer-assisted information storage and acquisition technologies leads to organizational intelligence that is more accurate, comprehensive, timely, and available.

Proposition 12: Use of computer-assisted communication and decision-support technologies leads to higher quality decisions.

Proposition 13: Use of computer-assisted communication and decision-support technologies reduces the time required to authorize proposed organizational actions.

Proposition 14: Use of computer-assisted communication and decision-support technologies reduces the time required to make decisions.

*George P. Huber, "A Theory of the Effects of Advanced Information Technologies on Organizational Design, Intelligence, and Decision Making," Academy of Management Review, 1990, Vol. 15, No. 1, pp. 47-71.

APPENDIX J.

HUBER'S THEORY OF ADVANCED INFORMATION TECHNOLOGIES

Advanced information technologies (independent variable) are devices:

(1) that transmit, manipulate, analyze, or exploit information;

(2) in which a digital computer processes information integral to the user's communication or decision task; and

(3) that have either made their appearance since 1970 or exist in a form that aids in communication or decision tasks to a significantly greater degree than did pre-1971 forms.

Note: Huber's proposed theory does not encompass the use of computer-assisted production techniques or the use of transaction-enabling technologies (e.g., computerized billing systems).

Dependent Variables in Huber's Theory

1. **Subunit Level**

    a. **Participation in decision making (1)**
    b. **Size and heterogeneity of decision units (2)**
    c. **Frequency and duration of meetings (3)**

2. **Organizational Level**

    a. **Centralization of decision making (4, 5)**
    b. **Number of organizational levels involved in authorization (6)**
    c. **Number of nodes in the information-processing network (7)**

3. **Organizational Memory**

    a. **Development and use of computer-resident data bases (8)**
    b. **Development and use of computer-resident in-house expert systems (9)**

4. **Performance Variables**

    a. **Effectiveness of environmental scanning (10)**
    b. **Quality and timeliness of organizational intelligence (11)**
    c. **Quality of decisions (12)**
    d. **Speed of decision making (13, 14)**

APPENDIX K.

HUBER'S MODEL OF EFFECTS OF ADVANCED INFORMATION TECHNOLOGIES ON ORGANIZATIONAL DESIGN, INTELLIGENCE, AND DECISION MAKING (1990)*

---------- DEPENDENT VARIABLES ----------

Design Variables (Subunit Level)	Design Variables (Organizational Level)	Design Variables (Organizational Memory)	Performance Variables
Participation in decision making (1)	Centralization of decision making (4,5)	Development and use of computer-resident data bases (8)	Effectiveness of environmental scanning (10)
Size and heterogeneity of decision units (2)	Number of organizational levels involved in authorization (6)	Development and use of computer-resident in-house expert systems (9)	Quality and timeliness of organizational intelligence (11)
Frequency and duration of meetings (3)	Number of nodes in the information-processing network (7)		Quality of decisions (12) Speed of decision making (13, 14)

Note: The related propositions for each design or performance variable are shown in parentheses.

*George P. Huber, "A Theory of the Effects of Advanced Information Technologies on Organizational Design, Intelligence, and Decision Making," Academy of Management Review, 1990, Vol. 15, No. 1, Table 1, p. 48.

APPENDIX L.

COMPETENCY INDICATORS FOR ARCHITECTURE AND ENGINEERING DESIGN FIRMS

1. An appropriate organizational structure is present for the support of advanced information technologies.

2. A training program exists to provide appropriate skills and knowledge to user personnel, and the training program is utilized by the organization.

3. Long-range technology planning is conducted on a regular, periodic basis at sufficient intervals to maintain currency with advanced information technology changes and innovations.

4. Technology planning focuses on the integration of all architecture and engineering disciplines within the firm's business objectives.

5. The level of technology embraced is consistent with the organization's mission and goals.

6. A recognition program exists to recognize and reward personnel for their achievements and accomplishments related to the effective use of advanced information technologies.

7. Proactive participation in industry or vendor-supported user groups and conferences is encouraged by the organization's management.

8. Standards related to the proper creation, archiving, and retention of information are documented and utilized by architecture and engineering personnel and supported by management.

9. Management is qualified in the use and capabilities of advanced information technologies, both internal and external to the organization.

10. Utilization of advanced information technologies focuses on the total design process, from concept, through design, and construction.

11. Information is deliverable to the firm's client in a timely manner and in the proper information media and format.

12. Archived information is organized in a manner such that specific project information can be retrieved in a near real-time manner and in the proper information media and format.

13. Advanced information technologies are leased or purchased based upon specific technology planning requirements.

14. **Security and backups of information are ensured through periodic project reviews and audits.**

15. **The advanced information technologies used produces demonstrated benefits to the firm's clients.**

APPENDIX M.

COMPETENCY ASSESSMENT OF ARCHITECTURE & ENGINEERING DESIGN FIRMS

ARCHITECTURE & ENGINEERING DESIGN FIRMS

COMPETENCY INDICATORS	FIRM A	FIRM B	FIRM C	FIRM D	FIRM E	FIRM F
	1		1	1	1	1
	2		2	2	2	
	3		3	3	3	3
	4		4	4	4	
	5	5				5
	6		6	6	6	6
	7	7	7	7	7	
	8		8	8	8	8
			9	9	9	
	10			10	10	
	11		11	11	11	11
	12		12	12	12	
		13				13
	14		14	14	14	14
	15			15	15	
TOTAL COMPETENCY SCORE	13	3	11	13	13	8

GLOSSARY

GLOSSARY OF ACRONYMS AND TERMS

Advanced Information Technologies. (AIT) Defined by George P. Huber (1990, *op. cit.*) as computer-based devices that have been in existence since 1970 and transmit, manipulate, analyze, or exploit information.

A&E or A/E. Architecture and Engineering.

AEC or A/E/C. Architecture, Engineering and Construction. [1]

AI. Artificial Intelligence; the capability of a computer system to perform functions analogous to human abilities of learning, reasoning, decision making, and self-improvement.

AIA. Architects Institute Association.

AIT. See Advanced Information Technologies.

Algorithm. Prescribed set of mathematical steps which is used to solve a problem or conduct an operation. [3]

AM/FM. Automated Mapping and Facilities Management.

AMT. Advanced Manufacturing Technology.

Annotation. The ability to attach notes to graphics or images by typing them in, using a light pen, or digitizing tablet. Useful for clarifying documents or editing images. [3]

ANSI. American National Standards Institute. A standards-setting, non-governmental organization, which develops and publishes standards for "voluntary" use in the United States. [3]

Aperture Card. A paper card the size of an IBM punch card with a rectangular opening that holds a 35mm frame of microfilm. Retrieval information can be punched into the card. [3]

Archive. A copy of data on disks, CD-ROM, mag tape, etc., for long-term storage and later possible access. Archived files are often compressed to save with storage space. [3]

ASCII. American Standard Code for Information Interchange; an 8-bit standard binary code used to encode keyboard characters and some special-purpose symbols. [1]

Associativity. A logical link between entities and/or attributes in a data base.

Attribute. In graphics, the condition a font is in - i.e., boldface, italic, underlined, reverse video - is its attribute. In MS-DOS, files can be assigned attributes that define how accessible it is - i.e., "read-only" is a file's attribute. In a document retrieval system, an

attribute of a file is one of the keys by which the document has been stored and indexed. [3]

BOM - Bill of Materials. [1]

Business Reengineering. Refers to the process of implementing organizational changes developed by analysis of basic business requirements and functions.

CAD. Computer-Aided Design; refers to the design of products, processes, or systems with the aid of a computer and graphics-oriented software. [1]

CADFAX. Computer-Aided Design and Facsimile; a facsimile device to transmit CAD drawings via public telephone communications systems.

CAE. Computer-Aided Engineering; refers to those technologies applied to the analysis simulation of engineering problems. [1]

CAFM. Computer-Aided Facilities Management. [1]

CAPE. Concurrent Art-to-Product Engineering.

CAR. Computer-Assisted Retrieval. Computer systems that locate or identify data stored on microfilm or paper. CAR systems rely on indexing and cross-indexing, pre-assigned to the documents, to find all documents related to the CAR search "attributes." [3]

CBIT. Computer-Based Information Technology.

CD. Compact Disc. A standard medium for storage of digital data in machine-readable form, accessible with a laser-based reader.

CD-ROM. Compact Disc - Read Only Memory. A data storage system using CDs as the medium. CD-ROMS typically hold more than 600 megabytes of data. [3]

CE. See Concurrent Engineering. [1]

Centralized. Processing all or substantially all of an enterprise's computing at one site, usually called the data center. The norm in U.S. business until the penetration of desktop PCs, which led the way to distributed processing. [3]

CIM. Computer-integrated Manufacturing.

COLD. Computer Output Laser Disk.

COM. Computer-Output Microfilm. The capability to directly produce microfilmed images from computer-generated signals. [2]

Compound Document - A document that contains information in several formats; text, graphics, and image. [2]

Computer Graphics. Sometimes referred to as interactive computer graphics; it involves the use of a computer to generate graphics of objects on a CRT screen.

Concept-based Clustering. A full-text retrieval search methodology based on document clustering. Documents are logically stored in a virtual storage area (clustering) based on document content and the defined relationship of terms to subject matter. [2]

Concept-based Retrieval. A textual search based on a concept rather than an exact word match. A concept automatically defines a list of search terms, phrases, and rules. [2]

Concurrent Engineering. A term coined by the Institute for Defense Analyses in 1986 to define a methodology for concurrently designing both the product and the processes for creating and supporting it.

CPU. Central Processing Unit. [1]

DBMS. Database Management System. [1]

Delphi technique. A qualitative forecasting technique that utilizes a panel of experts and a series of questionnaires to develop a forecast.

DIMS. Document Image Management System. See Imaging. [3]

DIP. Document Image Processing. See Imaging. [3]

DTP. Desk Top Publishing.

DXF. Data Exchange Format for exchanging files between CAD systems; developed by Autodesk Corporation. [1]

E&C. Engineering & Construction.

ECC. Engineering Change Control.

ECN. Engineering Change Notice.

ECO. Engineering Change Order. [1]

EDA. Electronic Design Automation. [1]

EDI. Electronic Data Interchange.

EDM. Electronic Document Management.

EIS. Electronic Imaging Systems.

Facsimile. FAX. Scanning device with integrated transceiver for communication of images over common carrier facilities. [2]

FAX. See Facsimile.

FEA. Finite-Element Analysis. [1]

FEM. Finite-Element Modeling. [1]

Full-text Retrieval. (FTR) A software or hardware process that retrieves textual documents based on the words, phrases, or concepts contained in the documents. Also known as Text Information Management Systems and Text Retrieval Systems. [2]

GIS. Geographic Information System.

GPS. Global Positioning Systems.

Groupware. Software which automates a single task among multiple workers. [2]

GT. Group Technology; involves the organizing and planning of production parts into batches that have some similarity in geometry and/or processing sequence.

GUI. Graphical User Interface. Computer control system that allows the user to command the computer by "pointing-and-clicking," usually with a mouse, at pictures, or "icons," rather than typing in commands. [3]

Hypermedia. A way of delivering information that provides multiple connected pathways through a body of information. Hypermedia allows the user to jump easily from one topic to related or supplementary material found in various forms, such as text, graphics, audio or video. [3]

Hypertext. A text retrieval search methodology based on associative memory process. Hypertext organizes textual information into sections known as nodes or chunks. [2]

ICR. Intelligent Character Recognition. See OCR. [2]

Imaging. The process of capturing, storing, and retrieving information, regardless of its original format using micrographics and/or optical disk technologies. See also DIP and DIMS. [2]

LAN. Local-Area Network. High-speed transmissions over twisted pair, coax, or fiber optic cables that connect terminals, personal computers, mainframe computers, and peripherals together at distances of about one mile or less. [3]

MCAD. Mechanical Computer-Aided Design.

MDA. Mechanical Design Automation.

Microfiche. A 105 x 148mm piece of microfilm on which images are arranged in a grid-like fashion. [2]

Microfilm. A fine-grain, high resolution film used to record images reduced in size from the original. [2]

Microfilm Scanner. A computer-based device for reading microfilm or film media and converting the images to digital form.

Microform. The general term for referring to a medium that contains micro-images. [2]

Micrographics. The branch of science and technology concerned with the methods and techniques for recording information on, and retrieving it from, microform. Those methods include reducing and recording images by photographic means, or directly onto film by computer (computer output microform, or COM); the location and retrieval of documents through indexing and mechanical means; and the display and magnification on display screens or paper output. [3]

MIME. Multipurpose Internet Mail Extensions; a protocol for transmission of "rich" text documents (sound, graphics, and text) over the Internet. See SMTP.

MPC. Multimedia PC. A standard hardware configuration for multimedia. [2]

Multimedia. A generic term referring to multiple media methodologies; e.g., paper film, magnetic, video.

OA. Office Automation.

OCR. Optical Character Recognition. The technique by which a document, that has been stored as an image, can be converted to ASCII or similar format.

OIS. Office Information Systems.

Paperless Systems. Computer-based systems and storage technologies that do not utilize paper for receiving, transmitting, or storing data.

PC. Personal Computer. Refers usually to an IBM Personal Computer or to an IBM-compatible computer. Sometimes used more generally to indicate any personal computer of any vendor or manufacturer. [3]

PDA. Personal Digital Assistant. Refers to laptop and notebook personal computers.

PDE. Product Data Exchange.

PDES. Product Data Exchange Standard. [1]

PDM. Product Data Management. [1]

Plastic Model. A model of a physical structure (e.g., building, process facility) constructed in plastic, wood, metal, or other materials.

RAID. Redundant Array of Inexpensive, or Independent, Disks. A storage device that uses several optical disks working in tandem to increase bandwidth output and to provide redundant backup. [3]

Scanner. A device that uses a narrow beam of light to digitize a document into a stream of bits. [2]

Seamless Systems. Refers to the electronic transfer of data without conversion to intermediate media.

SMTP. Simple Mail Transfer Protocol; a protocol for transmission of text files (usually ASCII) over the Internet. See MIME.

Softcopy. Refers to photographic and video imaging technologies for capturing and storage of data.

Text Information Management System. (TIMS). See Full-text Retrieval. [2]

Text Retrieval System. (TRS). See Full-text Retrieval. [2]

2D. Two-dimensional. Refers to the ability of a CAD graphics system to operate and display scalar vectors in two-dimensional space.

3D. Three-dimensional. Refers to the ability of a CAD graphics system to operate and display scalar vectors in three-dimensional space.

3D Modeling. Refers to the ability of a CAD graphics system to operate and display three-dimensional models.

Voice Mail. Storage of voice messages transmitted by telephone devices on magnetic recording media.

VR. Virtual Reality. Refers to the ability of a CAD graphics system to operate and display graphical views in a near-real fashion. It also connotes the ability to manipulate objects or views in a nearly instantaneous fashion.

WAN. Wide-Area Network. [1]

Whole Text Retrieval. Refers to the ability of a computer-based information system to store and retrieve the entire text from documents or files.

Wireless LAN. Wireless Local Area Network.

Workflow. The automation of a business process or procedure. Based on pro-active management of electronic documents. [2]

WORM. Write Once Read Many. A characteristic of any digital storage medium on which information can be recorded once and read many times thereafter. [2]

WP. Word Processing.

Glossary Sources:

[1] Computer-Aided Engineering magazine, December 1993, p. 80.

[2] "Terms, Concepts & Acronyms Used in the Electronic Document Management Systems Industry," Delphi Consulting Group, Inc., Boston, MA, 1992.

[3] "The Imaging Glossary: Electronic Document & Image Processing Terms, Acronyms and Concepts, Andy Moore, Telecom Publishing, New York, NY, 1991.

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