DESIGN AND CONSTRUCTION AUTOMATION:

COMPETITIVE ADVANTAGES AND MANAGEMENT CHALLENGES

by C.B. Tatum, Professor of Civil Engineering
Stanford University, Stanford, CA 94305-4020, USA

Abstract

Many new demands in the construction industry encourage increased automation of design and construction, but realizing the opportunity presents many management challenges. One of the greatest is awareness of potential advantages for the firm. The purpose of this paper is to describe the possible competitive advantages from advanced technologies for design and construction automation and to identify management challenges of acquiring and implementing these technologies. The paper presents a brief review of experience with technologies for automation and then describes potential competitive advantages and strategies to acquire and effectively implement these technologies. The conclusions highlight a need for vision concerning how automation will change constructed products, processes, and owner's requirements.

INTRODUCTION

In the past, technical excellence in the relevant engineering disciplines was the key to winning contracts to design major facilities. Knowledge of world markets and key suppliers brought success in procurement. Construction competence and relevant experience won the opportunity to build challenging projects. These capabilities are still necessary but rapidly becoming insufficient to compete in design and construction markets. Success now requires considering competitive forces for change, what the firm is doing (not just how) and ways to apply new technologies such as automation.

New technologies for automation offer many competitive advantages, but also present many management challenges. One of the greatest is awareness that design and construction automation both improve operations—the traditional motivation for new technology—and provide new sources of competitive advantage—the unrealized opportunity. The purpose of this paper is to describe the possible competitive advantages from advanced technologies for design and construction automation and to identify management challenges of acquiring and implementing these technologies. It is based on findings from an ongoing investigation of construction innovation and using advanced advanced technology for competitive advantage in construction, including analysis of successful experience with computer-aided engineering and technologies to partially automate construction operations. The Center for Integrated Facility Engineering (CIFE), a joint research effort located at Stanford University, is also conducting related research concerning the competitive advantages and management challenges of using advanced computer technologies to assist in vertical integration of facility construction projects.

The paper first presents a brief review of manufacturing, design and construction experience with technologies for automation to date. The major sections then describe potential competitive advantages from new technology for design and construction automation and strategies to acquire and effectively implement these technologies.

EXPERIENCE WITH TECHNOLOGIES FOR AUTOMATION

Experience in manufacturing, design, and construction regarding the initial use of technologies for automation is a useful background for examining potential competitive advantages and management challenges. The scope of this paper does not allow even a complete summary of this interesting experience with automation, but some of the most relevant findings are listed below.

Automation in Manufacturing

The automation of product design and production operations has been a major emphasis in many industries. To date, the results are mixed. Investigations have revealed the following results and problems [1, 3]:

- The technological potential for integration is under-exploited.
- Realizing the potential competitive advantages requires resolving several organizational and managerial issues.
- Several levels of "organizational learning" are needed to take advantage of technologies for automation.
- This learning must continue as markets and technologies change.
- Management makes the difference in using new technologies to improve manufacturing performance.

Automation in Design of Constructed Facilities

The automation of design for buildings, plants and other constructed facilities is proceeding rapidly in several segments of the Architecture, Engineering, and Construction (AEC) industry. Investigations have revealed several interesting findings regarding the incentives, process, and results of design automation [5]:

- Although design automation has reduced work hours, it has often not been cost effective for design.
- Design automation has produced significant "downstream" benefits, such as reduced field rework, easier startup, shorter schedules, and increased prefabrication.
- The major needs to increase design automation are industry standards, and increased attention to the people issues.
- Fragmentation of the AEC industry increases both the need for technology to automate and integrate and the difficulty of diffusing this technology [4].

COMPETITIVE ADVANTAGES FROM AUTOMATION TECHNOLOGY

Many forces in the AEC industry appear to be shifting the major basis of competition by requiring new capabilities to design and construct new types of facilities. These forces include both "market pull" forces such as owner's needs for more complex facilities and "technology push" forces that stem from the availability of several new types of technology. Among the technology push forces, design and construction automation appears significant. Firms with this capability may win new projects based on the types of competitive advantages shown in Figure 1. As they are now described, these potential competitive advantages are based on application of generic strategies developed by Porter [8, 9] to the AEC industry. They also consider insights developed in an ongoing investigation of innovation and using technology for competitive advantage in construction [11, 12, 13].

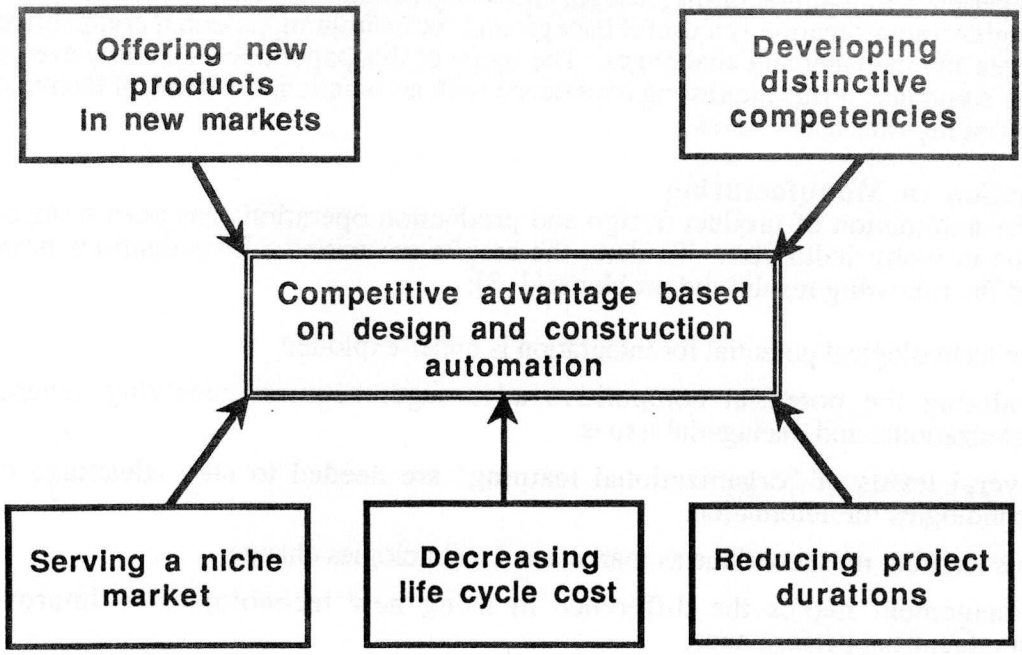

Figure 1. Potential Competitive Advantages From Design and Construction Automation

Offering New Products in New Markets

Automation will help design and construction firms respond to the needs of owners for changing facilities. As the complexity of constructed products increases, more specialists working with more complex tools will be required. It may prove extremely difficult to adequately coordinate these specialists without new computer technology. Computer-based integration may also allow design and construction firms to offer value in non-traditional markets, such as a system engineering function to coordinate the design, startup and initial operation of complex manufacturing facilities.

Developing Distinctive Competence

Computer-aided engineering (CAE) systems will offer a desirable new capability for coordination either within a firm or between differing firms working together on a project. The ability to offer information for earlier and easier visualization and evaluation of design concepts, to anticipate the consequences of design decisions, and to consider multiple alternatives is an important distinctive competence and a potential advantage based on automated design. In addition to the advantages for design, project databases can better support decisions in planning and financing for projects.

CAE systems can also bring advantages based on improved coordination with external organizations. The ability to provide increased information to regulatory agencies can improve these interfaces and expedite approvals. Electronic interfaces with vendors will provide a distinctive competence for progressive design firms. As construction automation increases, the ability to produce designs that support process automation will become another important advantage.

Although the technology is now at an early stage, it appears that automation can provide several distinctive competencies for construction firms. These include increased potential for shop work, ability to perform specialized tasks and satisfy stringent quality requirements, improved safety, and decreased workforce requirements. These are examples of advantages other that lower cost.

During the completion phase of the project, facility managers need new types of information that advanced computer applications can provide. They now often require a CAE database of the design, updated to include all as-built changes, at project completion. This will provide a basis for operation, maintenance, and subsequent modification. Owners of buildings are also beginning to use similar information in a CAE database to plan space utilization and to make administrative calculations such as overhead rates and billing.

Reducing Project Duration

Manufacturing, hydrocarbon processing, environmental, and electric energy projects are often schedule driven. Owners need to delay investments to the last minute and then need new capacity at the earliest possible date. Market windows are very short. Court orders often set required operational dates for environmental facilities and impose large fines if they are not met. Therefore, shortened overall schedules for design, permitting, procurement, construction, and startup will be a major priority for facility owners.

CAE systems offer the potential to shorten design schedules and to support increased integration that will allow greater overlap of the engineering, procurement, and construction phases of a project. Increased use of devices for automation of fabrication and assembly operations will also shorten construction durations.

Decreasing the Life Cycle Cost of the Project

Integrated CAE systems prompt and allow a broader view of project cost. This provides benefits for owners who operate facilities. Making data concerning operation and maintenance from similar projects available during planning and design of new facilities can support decisions based on life cycle cost rather than the priorities of a specific discipline. Therefore, design automation can give competitive advantages based on a broader view of value for the owner.

These examples illustrate the important potential competitive advantages from automation. Based on the changes that are currently underway in AEC markets, many others appear possible. Realizing this potential requires functional strategies to acquire technology and use it to support the competitive strategies of the firm.

Acquiring Technology for Automation

The background from other industries and the examples of successful innovation in design and construction suggest strategies for the development of advanced technology [13]. A technology strategy is a plan for actions and commitment of resources to either acquire a new technology or use advanced technology to gain competitive advantage. The technology strategies serve as one of the functional strategies (along with human resources, finance, marketing, and others, see Figure 2) that support business and corporate strategies. The following technology strategies describe possible ways to acquire technology automation.

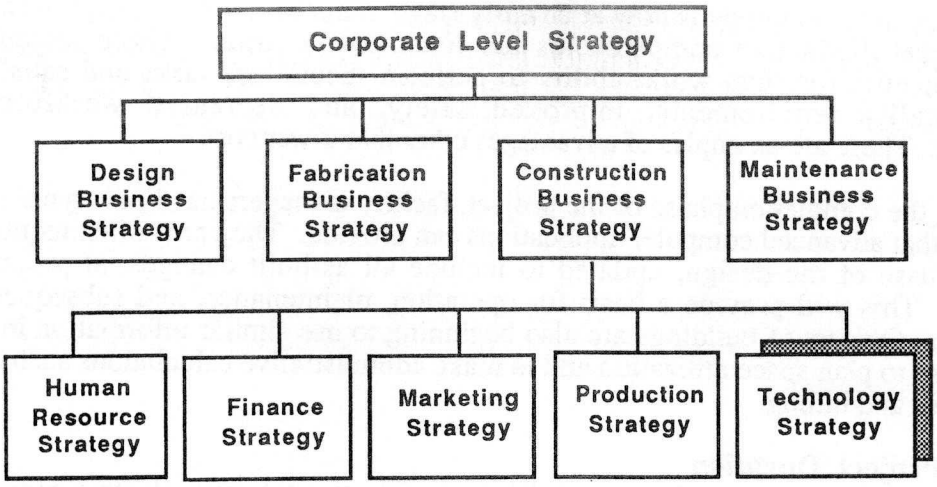

Figure 2. Levels of Strategy for a Diversified Firm

Interact with a Lead Developer of Automation Technology

Designers or contractors can work with lead suppliers to develop new technologies for automation. This involves identifying needs for new technology based on operational improvements or desired competitive advantages, convincing a progressive firm that developing the technology could offer an opportunity for sales to others, and working with this firm to help develop and initially implement the advanced hardware or software. The developer brings expertise in the relevant technology and the designer or contractor provides a real-world test bed. The user must keep the process active to gain further advantages when the technology is adopted by others.

Several engineer-constructors have used this strategy in working with developers of advanced software for CAE. They have defined capabilities and features needed to satisfy their needs and assigned knowledgeable users to participate in the suppliers development activities. In an early example from construction, a contractor worked closely with a specialty firm to adapt laser technology for the partial automation of fine grading operations [14].

Conduct Internal Development or Sponsor External Development

The development of new technology tailored to the needs of the firm and its customers may require investments in research and development activities. These activities can range from major R&D laboratories to focused efforts to develop a specific new computer program or machine. This strategy involves setting priorities based on the problems of existing operations or potential competitive advantages and developing new technology internally or by contracting with specialty firms. Many design and construction firms are now using this strategy to develop 3D CAD systems and enhancements for access to the data in these systems, database systems for functional and administrative data, and early applications of AI. Several firms have made significant efforts to develop advanced computer technology [2, 7].

The results of research performed at universities and in private firms will provide another basis for advanced computer technology to support design and construction automation. Involvement in the research projects, facilitated access to the results, and the opportunity to take the concepts and prototype systems into the firm for further development are major advantages of industry participation in these research efforts.

Improve Processes for Repeated Operations

Consistent, intense, and unyielding efforts to improve operations that are required over several projects can produce new technology. This strategy involves aggressively seeking incremental improvements of existing technology and using available technology in new ways. A small mechanical contractor specializing in heating and ventilating ductwork provided an example of this strategy. Frustrated by low productivity in detailing the configuration of ductwork and in fabricating the sheet metal, he adopted and greatly extended technology to partially automate each of these operations. A microcomputer system with a library of industry standard shapes greatly improved the productivity of detailing ductwork. Linking this computer system with selected machines in the fabrication shop substantially increased the productivity of fabrication operations. Based on this early automation of design and fabrication, the contractor became a low cost supplier of ductwork for his former competitors.

Drive Technology Development on Specific Projects

The challenges of specific construction projects offer a powerful incentive for the development of advanced construction technology. Project teams can produce innovative solutions to the problems created by demanding technical, cost, schedule, or quality requirements. One contractor extended and partially automated the segmental technique for outfall installation to gain several advantages on a project [10].

Interact With Owners and Operators

A designer or contractor can develop new technologies for automation by establishing strong links with owners to determine specific needs. This strategy creates differentiation by unique capability to meet the owners special needs. For technologies related to design or construction automation, this interaction can guide a designer's development of CAE systems and graphics for visualization of major design concepts that will allow the owner to consider many alternatives. Some firms are even using new computer tools at the proposal stage for major projects.

Operators of buildings or plants, whether a part of the owner's organization or separate, offer another important opportunity for improvements based on integration. Designers or contractors can work with operators to identify special needs and develop new technology to satisfy these needs. Definition of information needs for operation, maintenance, and administrative control of facilities by operators can guide development of 3D CAD databases to support the use of the facility. The administrative portion of these databases can also assist in record keeping for use of the space.

MANAGEMENT CHALLENGES OF AUTOMATION

Realizing the many potential benefits of design and construction automation presents challenges for owners and operators, designers and contractors, technology developers and suppliers, and researchers.

Facility Owners and Operators

Owners have both the most to gain and the greatest leverage to realize the potential benefits from design and construction automation. This requires a vision of future facilities and the capabilities needed to design and construct them [15]. For design automation, making the use of CAE a prerequisite to competing for projects will focus attention on this technology. Owners and operators can also encourage construction automation by considering efforts to maximize offsite assembly and increase productivity of installation as an important criterion in selecting contractors.

Without changes, the institutional framework of the AEC industry will stand in the way of owners realizing the potential benefits of automation. Existing divisions of responsibility, forms of contract, and even laws may not support the most effective use of this new technology. Examples of possible actions by owners include: shifting responsibilities to the organizations that can most effectively automate; altering contracts to recognize new technology for automation and to provide new incentives; and revising assignment of liability. A major challenge is to find a way to encourage designers to use a technology that largely benefits construction.

Designers and Contractors

Nurturing the technology for design and construction automation requires looking past immediate justification and payback to future benefits and competitive necessity. One engineering manager and CIFE participant put it bluntly: "The decision is no longer do you invest in CAE; now it is do you want to be in the business." For design automation, encouraging signs indicate that leading firms are moving from a traditional role of "technology broker" [6] to active participant in development. Although the technology for construction automation lags, developing a similarly progressive attitude in contractors' organizations will be a key management challenge.

The dynamics of integration technology will require a "learning organization" [3] that can anticipate and benefit from the frequent changes in technology that now cause so much frustration. This means accepting change as both the needs of customers and the technologies available change, preparing to use this dynamic state to gain advantages, and providing for effective organizational response.

Technology Developers and Suppliers

Suppliers of automation technology have a vital role in providing advanced hardware and software that meets the demands and realizes the potential for design and construction automation. The needs range from significant increases in the scope and performance of CAE and related computer systems to solving the tough problems of developing hardware that will successfully automate highly diverse construction operations performed under variable conditions.

Researchers

Many challenges remain for researchers seeking to provide a fundamental basis for design and construction automation. The needs range from making fundamental advances in databases, AI, and robotics to providing a conceptual basis for the hardware that will successfully automate highly diverse construction operations. Increased understanding of ways to gain competitive advantage, strategies to acquire automation technology, organizational implications of design and construction automation, and ways to effectively implement new technology is needed.

CONCLUSIONS

Design and construction automation offer the potential to satisfy the needs of owners and therefore provide significant competitive advantages. Many alternatives are available to firms seeking to acquire this technology, ranging from internal development to cooperative efforts. All of the major participants in construction projects can win with increased automation. But each has a strong management challenge.

ACKNOWLEDGEMENTS

This paper is based on research funded by the Structures and Building Systems Program in the Division of Mechanics, Structures, and Materials Engineering of the National Science Foundation and by the Center for Integrated Facilities Engineering at Stanford. This support is gratefully acknowledged.

REFERENCES

1. Adler, Paul. (1988). "The Managerial Challenges of Integrating CAD/CAM," Draft Research Report, Department of Industrial Engineering, Stanford University.
2. Breen, W. C, and Kontny, V. L. (1987). "Automation's Impact on Engineering Design Progress," *Journal of Management in Engineering,* 3(4), 275-280.
3. Hayes, Robert H., Wheelwright, Stephen C., and Clark, Kim B. (1988). *Dynamic Manufacturing,* The Free Press, New York.
4. Howard, H. C., R. E. Levitt, B. C. Paulson, Jr., J. G. Pohl, and Tatum, C. B. (1989). "Computer Integration: Reducing Fragmentation in the AEC Industry," *Journal of Computing in Civil Engineering,* ASCE, 3(1), 18-32.
5. Ibbs, C. W. (1989). "Cost Effectiveness of Computerization in Design and Construction," Research Report, University of California, Berkeley, CA.
6. "International Competition in Services." (1987). Office of Technology Assessment, Washington, D.C.
7. Killen, Timothy S. (1988). "Design Tools for Construction," presentation to a National Academy of Engineering Workshop, Woods Hole, Mass., August.
8. Porter, Michael E. (1980). *Competitive Strategy,* The Free Press, New York.
9. Porter, Michael E. (1985). *Competitive Advantage,* The Free Press, New York.
10. Stewart, William S., Tatum, C. B. (1988). "Segmental Placement of the Renton Outfall: A Construction Innovation," *Journal of Construction Engineering and Management,* ASCE, 114(3), 390-407.
11. Tatum, C. B. (1986). "Potential Mechanisms for Construction Innovation," *Journal of Construction Engineering and Management,* ASCE, 112(2), 178-191.
12. Tatum, Clyde B. (1987). "The Process of Innovation in the Construction Firm," *Journal of Construction Engineering and Management,* ASCE, 113(4), 648-663.
13. Tatum, C. B. (1988). "Technology and Competitive Advantage in Civil Engineering," *Journal of Prof. Issues In Engineering,* ASCE, 114(3), 256-264.
14. Tatum, C. B. and Funke, A. T. (1988). "Partially-Automated Grading: A Construction Process Innovation," *Journal of Construction Engineering and Management,* ASCE, 114(1), 19-35.
15. Valentine, Robert. (1988). "CII Annual Conference Closing Remarks."