VALUE OF CONCURRENT ENGINEERING FOR A/E/C INDUSTRY

By Jesus M. de la Garza, Associate Member, ASCE, Primo Alcantara Jr., Munish Kapoor, and P. S. Ramesh

ABSTRACT: Producing constructed facilities of the highest quality in a cost-effective environment will benefit not only owners and end users, but also all participants engaged in the conception, design, construction, operation, maintenance, rehabilitation, or decommission phase of its life cycle. Cost-effective and top-quality facilities can be conceived, designed, built, and operated if these activities are not performed in a vacuum, but rather, performed in a life-cycle context. Concurrent engineering is a philosophy, which is conducive to true life-cycle analysis. It brings together, from project inception, multiple individuals to address all angles of a project and enables the accumulation of knowledge and information so as to reduce downstream risks and anticipate constructability, operability, and maintainability expectations. Aspects of concurrent engineering are already practiced in the architecture/engineering-construction (A/E/C) industry in the form of Total Quality Management (TQM), constructability reviews, and partnering. Other aspects like multifunctional team formation, macrolevel reorganization, and computer-based cooperative and distributed design still have not been adopted. This paper suggests that the A/E/C industry should continue adopting more facets of the concurrent engineering paradigm. Concurrent engineering can turn the industry's high degree of fragmentation and specialization into a strength, as opposed to a current debility.

INTRODUCTION

The architecture-engineering-construction (A/E/C) industry is one of the largest industries in the United States accounting for as much as 9-10% of the gross national product (GNP) (Oglesby 1989; U.S. Bureau 1991). The A/E/C is broadly divided into five project-type categories: residential, commercial, industrial, highway and heavy, and marine. Structures typically have life spans of 25 yr or more. Conception, design, construction, operation, maintenance, rehabilitation, renewal, and decommissioning are the various phases in the life cycle of constructed facilities. The average number of employees in a construction firm is about 10 and 75% of the firms have four or less employees (Oglesby 1989). Given this aspect of the industry, it is not possible for a single A/E/C firm to perform diverse work in all life-cycle phases of a project or even to claim an expertise niche in all five project-type categories.

This paper advances the concept of concurrent engineering as a philosophy which has the potential to reoptimize, reenergize, and refuel the A/E/C industry. Concurrent engineering is a philosophy that systematically incorporates planning for all phases of the life-cycle project at its very inception. Concurrent engineering advocates that participants from all phases of the life cycle play an active role right from the conception and planning phases. If adapted and adopted properly, concurrent engineering could make it possible for the entire A/E/C industry to once again reap the benefits derived from its highly fragmented and specialized nature.

This paper summarizes features of the A/E/C industry, which are relevant in a concurrent-engineering context, outlines core principles on which concurrent engineering is based, and begins an open-ended discussion about some changes that need to take place in the A/E/C state of the practice to adopt and adapt to concurrent engineering.
STATE OF THE PRACTICE IN U.S. A/E/C INDUSTRY

To provide a context for open-ended conclusions, pros and cons of fragmentation and specialization, the spectrum of organizational structures, upstream and downstream life-cycle activities, traditional contractual arrangements, means of exchanging project information, and the role of computers are examined.

Fragmentation

Owners, design firms, construction firms, material suppliers, bankers, lawyers, government agencies, end users, facility operators, maintenance teams, and demolition firms are some of the participants involved in the life cycle of any constructed facility. The degree of fragmentation in the A/E/C industry is exemplified by the following two examples: 2,400 contractors, subcontractors, fabricators, suppliers, and vendors were involved in the new Pittsburgh International Airport (Moorcroft 1993) and 125 contractors and suppliers were involved in the Mall of America project in Minneapolis (Cosgrove 1991). Current practice, though, involves only a fraction of these participants within each project's lifecycle phase. Traditionally, for example, the design phase only involves the owner and the design team with negligible participation from the construction team. Howard et al. (1989) noted that the A/E/C industry's emphasis on specialization caused fragmentation. The goal of differentiation and specialization within the industry was to promote technological innovation. A system was divided into subsystems within which were people who were experts in their fields. Specialization allowed greater flexibility and increased productivity during the 1960s. However, as the degree of specialization increased, the problems associated with fragmentation, like breakdowns in the communication infrastructure, began to negate the benefits of specialization (Howard et al. 1989). It can be further speculated that diminished loyalty toward the ultimate customer of constructed facilities, i.e., the owner, has also been a by-product of excessive fragmentation. The claim-conscious attitude of most project participants attests to this speculation.

Fragmentation has also resulted in intense competition because of the large number of specialized firms in the A/E/C industry. Bidding on a project is highly competitive, yet expected productivity improvements associated with competition are not apparent. In fact, productivity has been static for almost two decades (Muspratt 1988). A highly competitive environment has forced companies to avoid risks and adhere to industry norms whenever possible (Mohan 1990). Conducting research and development as well as investing in new and untried technologies are not usual industry practices (De La Garza et al. 1991). Howard et al. (1989) noted that there is a sharp contrast between the research and development policies of the U.S. A/E/C firms and their foreign counterparts. These foreign firms invest large amounts of time and money in research and development and as a result, they have already surpassed the U.S. firms in advanced construction technologies, like building-construction automation.

Can concurrent engineering realign the A/E/C industry by overcoming the disadvantages of, while benefiting from, its existing fragmentation and specialization?

Organizational Structures

There are three types of organizational structures popular today, project organization, functional organization, and matrix organization. Figs. 1–3 depict the three types of organizational structures (Blanchard 1990). Tables 1–3 (Blanchard 1990) enumerate the advantages and disadvantages of each of these structures. All firms in the A/E/C industry fall within the spectrum bounded by these organizational types. While small firms typically have a project-organizational structure, medium and large A/E/C firms typically have either the functional or the matrix-organizational structure.

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**Organizational Structures**

- **Project Organization**
- **Functional Organization**
- **Matrix Organization**

**TABLE 1. Project Organization Structure**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Clearly defined lines of authority and responsibility for a given project</td>
<td>Application of new technologies tends to suffer without strong functional groups and opportunities for communication</td>
</tr>
<tr>
<td>Strong customer orientation</td>
<td>Duplication of effort in large contractor organizations</td>
</tr>
<tr>
<td>Personnel loyalty to a project is high</td>
<td>Difficult to shift personnel in response to needs</td>
</tr>
<tr>
<td>Required expertise can be assigned and retained</td>
<td>Individual career growth may suffer</td>
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TABLE 2. Functional Organization Structure

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Better technical capability</td>
<td>Lack of customer orientation</td>
</tr>
<tr>
<td>Quicker organizational response</td>
<td>Tailoring technical requirements to a particular project is discouraged</td>
</tr>
<tr>
<td>Easier budgeting and control</td>
<td>Difficult to maintain identity with a specific project</td>
</tr>
<tr>
<td>Good communication channels</td>
<td>Less personal motivation to excel (because of group orientation of expertise)</td>
</tr>
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</table>

TABLE 3. Matrix Organization Structure

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Project manager can provide strong project controls while having ready access to resources from many technical departments.</td>
<td>From worker perspective, there is often a split in the chain of command for reporting purposes (project boss versus functional boss).</td>
</tr>
<tr>
<td>Technical expertise can be exchanged between projects with minimum conflict.</td>
<td>Each project organization operates independently—possible duplication of resources.</td>
</tr>
<tr>
<td>Authority and responsibility for task accomplishment are shared between project manager and functional manager. There is mutual commitment in fulfilling project requirements.</td>
<td>Both project and functional areas of activity require similar administrative controls (more costly from company standpoint).</td>
</tr>
<tr>
<td>Key personnel can be shared and assigned to work on a variety of problems (more effective use of personnel from company standpoint).</td>
<td>Balance of power between project and functional organizations must be clearly defined and maintained.</td>
</tr>
</tbody>
</table>

FIG. 4. Partial A/E/C Macrofirm Functional Organizational Structure

At the macrolevel, however, the A/E/C industry operates primarily as a functional organization. Fig. 4 illustrates this concept by considering all the project participants within one macrofirm. As shown in Table 2, lack of customer orientation is one of the disadvantages of functional organizations since the various firms act merely as representatives of their individual organizations rather than as partners in the macrofirm working for the benefit of the owner. For example, as explained in the film “Skyscraper: The Worldwide Plaza,” while designers pride themselves in designing a facility that meets or exceeds the owner’s requirements, constructors pride themselves in building such a facility within the imposed constraints of time, cost, and quality. However, an even better and more efficient facility may be possible if designers and constructors were to cooperate and collaborate for the benefit of the project, instead of primarily representing their respective organizations. In other words, the result of good partners working together towards shared goals and objectives is far greater than the sum of the products, however good, of individual participants working in many instances with conflicting agendas.

How would this macrofirm look within a concurrent-engineering paradigm?

Upstream Activities

Upstream life-cycle activities include conception, specification, and design. Initially, the owner conducts a feasibility study and decides to proceed with the project based on favorable factors obtained from the study. The owner develops project requirements based on needs and available resources.

The architects and the design engineers (A/Es), in consultation with the owner, develop construction documents, which include detailed specifications and drawings. Formal design reviews are carried out during design development. Value-engineering analysis is also performed during design-review sessions. Owners use the construction documents to invite bids from qualified contractors. Owners typically award the contract to the lowest bidder who is then termed as the general contractor. The present method of awarding construction contracts to low bidders forces construction firms to minimize overhead costs, such as research and development costs (Kennedy 1992). Usually, the general contractor executes only a part of the work and subcontracts the rest to various other organizations. Often, the list of subcontractors has to be reviewed by the owner before the contract is awarded to the general contractor. The general contractor and the owner then sign a contract. Coordination between the various participants is usually achieved through a preconstruction conference. Schedules, as well as means and methods of construction, are discussed so that any conflicts can be detected and remedial measures taken. Under this method, the A/E is retained by the owner to act as its representative and the coordinate and inspect all work done by the contractor. Practitioners have termed this way of procuring facilities the “tossed over the wall” method. In this method, A/Es prepare drawings and specifications without input from contractors. These documents are then figuratively thrown over an invisible wall to the contractors for execution. This method is unproductive yet one of the more popular contractual arrangements.

Can concurrent engineering contribute to the tearing down of the invisible wall between the A/Es and contractors?

Downstream Activities

Downstream activities include construction, operation, maintenance, and decommissioning. Construction is a fairly complicated industry in that there is bound
to be certain actual conditions that will be different from previously agreed ones. This could be due to owner-imposed changes, incomplete designs, differing site conditions, unavailability of resources, misinterpretation of contract documents, unsuccessful methods of construction, unconstructable designs, etc. It does not take long to conclude that often these scenarios, now common on every project, result from a lack of coordination and collaboration between the various parties responsible for the conception, design, construction, and operation of a facility.

Owners of constructed facilities would be better served if designs were developed taking into consideration not only functional, performance, and scope requirements, but also, constructability, operability, maintainability, and renewability issues, i.e., a true life-cycled design.

Does concurrent engineering offer a philosophy that is conducive to true life-cycle analysis?

**Contractual Arrangements**

The U.S. A/E/C industry implements many different kinds of contractual arrangements. The most popular form is the traditional separate design-construction contract. In this type of contractual arrangement, the owner retains an A/E firm to design a facility and produce construction documents. The owner selects the A/E firm based primarily on the firm's technical competence and on a negotiated fee for its services. After the completion of the design, the owner invites bids from prequalified or otherwise at-large contractors. In traditional lump-sum or unit-price contracts, the owner contracts with the lowest bidder. Unlike the designer-selection process, the major consideration in the contractor selection is price.

Other less popular forms of contractual arrangements are the integrated design-build contracts and the construction-management contracts. Similar to the designer-selection process in the traditional separate design-construction contractual arrangement, the owner selects an integrated design-build firm based on professional qualifications. The design-build firm is responsible for the entire design and construction of the owner's required facility. The owner and the design-build firm negotiate on the fee for the latter's services. This arrangement is not prevalent in the fragmented A/E/C industry because of the limited number of integrated design-build firms. In construction-management contracts, the owner retains a construction-management firm to oversee the design and construction of the proposed facility. The owner selects this firm based on professional qualifications and pays a negotiated fee. This firm then utilizes either the traditional separate design-construction approach or the integrated design-build approach in acquiring design and construction services.

Would concurrent engineering foster an environment whereby small firms could quickly form joint ventures to effectively respond to design-build request for proposals (RFPs)?

**Means of Exchanging Project Information**

When it comes to disseminating project information, computer usage in the A/E/C industry has merely changed the paper-generation process. We have switched drafting boards, lead pencils, and ink pens to computers armed with computer-aided design (CAD) software and plotters. Computers not only have altered the paper-producing process, but they have also expedited it. Producing a CAD-based D-size drawing takes a fraction of the time it takes to produce it on a drafting board. The end result is that computers have afforded the efficient production of more paper. While this may seem like a step in the right direction, it is actually becoming a step backward because the power of CAD tools is being strangled by the delivery means, i.e., paper. It is not uncommon anymore to find CAD-based paper-printed drawings produced by collapsing an unreasonable number of CAD layers in a single sheet. This practice renders the paper-printed drawings unreadable and useless, which in turn leads to misinterpretation, omissions, rework, poor quality, and higher uncertainty. This practice certainly constitutes a misuse of the technology, yet forced by the need to "include everything in a drawing" and by the need to deliver it via paper. Furthermore, the paper information-exchange problem results in increased project life-cycle costs, decreased productivity, and decreased project performance (Howard et al. 1989). Thus, there is a need for a better mode of exchanging project information.

Does computer-aided concurrent engineering offer an environment for the electronic exchange of project information?

**Use of Computer Technologies**

The A/E/C industry widely uses various computer technologies in its activities. Choi and Ibbs (1990a, 1990b) noted that the industry uses computers for administration, accounting, design, engineering analysis, project management, and marketing activities. Their findings showed that the use of computers allowed individual companies to increase their productivity. However, there was no significant increase in the overall productivity, considering all the participants involved in a project.

Designing in two-dimensional (2D) graphical-computer representation is already prevalent in the industry. There are, on the other hand, only a limited number of firms employing computerized three-dimensional (3D) modeling techniques. Research done jointly by Columbia University and Stone & Webster Engineering Corporation proved that 3D modeling is superior to 2D. Their research involved transforming an almost complete 2D design of a building into a 3D-computer model. This transformation eliminated numerous inconsistencies in the 2D-design representation. Their research also showed that 3D modeling increases the constructability and schedulability of designs, as well as enhances construction planning, training, and monitoring. All these benefits ultimately lead to the increase of construction productivity (Reinschmidt et al. 1991). However, 3D computer modeling techniques are atypical to the
A/E/C industry, being implemented only by the larger and/or more innovative firms, Bechtel Corp., Stone and Webster Engineering Corp., Rust International, Fluor Daniel, Brown and Root, among others.

What is the role of computers in supporting the implementation of concurrent engineering?

Need for Transformation

One of the major drawbacks in the current state of the practice is that most of the defects in a facility’s design are not noticed until the structure is actually being constructed, operated, or maintained. It has been estimated that rework constitutes 12.4% of the total installed-project cost in industrial projects (“Costs” 1989). If this were the case for all five project-type categories, then construction rework could represent a staggering 1.2% of the gross national product (GNP).

The need for transformation is also necessary to get rid of the stereotypes that have bred cultural impediments to cooperative-product development. An example of such stereotypes is typified by the relative position of a phase in a project’s life cycle (Sprague 1991). The further along a function falls in the life cycle of the facility, the less information it needs for decision making, hence the lower its value to an organization. Concurrent engineering is conducive of a leveled field so that every player involved in a facility’s life cycle can contribute on an equal basis.

The construction industry has to look for alternative methods and philosophies to remain competitive in domestic and international markets. One of the alternatives to rectify the situation is to automate those tasks that are technologically and economically feasible. The other alternative is to modify the basic A/E/C procurement process by augmenting it with the philosophy of concurrent engineering. Foreign firms have implemented both of these alternatives with great success. A study on concurrent engineering practices was conducted in Europe with startling results. Some of the more significant results are a 30%–42% reduction in manufacturing costs, 75% reduction in scrap and rework, 35%–60% reduction in the time it takes to develop an artifact, 30%–87% reduction in defects, and 30%–60% increase in savings (Creese 1990). Although this study was not conducted for the construction industry, it provides an example of how the concurrent engineering philosophy can help increase the competitiveness of a company.

In the present setup of the industry, the norm is to design, build, then rework. Such a method is time and money consuming and reduces competitiveness. The time seems right for a major renaissance of the U.S. A/E/C industry. Concurrent engineering may be it.

**CONCURRENT ENGINEERING**

Figs. 5(a) and 5(b) depict typical attitudes towards designing, engineering, building, and operating constructed facilities during the last two decades. Intrinsically to these attitudes is the notion of increased rework during construction as well as increased costs during operation, maintenance, and rehabilitation. In the 1990s and beyond, there is a need to revamp the facility-development process for the U.S. A/E/C industry to remain competitive in both domestic and international markets. Fig. 5(c) represents not only the next logical evolution phase from the 1980s paradigm, but also represents a complete reverse perspective on the facility-development process, which prevailed in the 1970s and earlier.

**What is Concurrent Engineering?**

There is no agreement among experts as to the exact definition of concurrent engineering. The following definition taken from the mechanical, electrical, and industrial-engineering disciplines explains the concept rather succinctly:

"Concurrent engineering is defined as a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal including quality, cost, schedule and, user requirements" [CERC (1992), page 3].

In layman terms, concurrent engineering can be defined as a philosophy which systematically incorporates planning for all phases of the project life cycle at its very inception. Concurrent engineering advocates that participants from all phases of the life cycle play an active role right from the conception and planning phases.

Fig. 6 illustrates the concurrent engineering concept by depicting the concurrence nature in the facility-development process (Rosenblatt 1991). It can be seen from this figure that a significant amount of extra work takes place during the design phase. This is in contrast to the traditional sequential process depicted in Fig. 7 (Lee 1992). The concurrent engineering philosophy supports the paradigm shift outlined in Fig. 5(c) by firstly and directly answering the "is it the best?" and "will it work?" questions before a facility is actually built.

The implementation of such a radically different philosophy requires a different kind of organizational structure and culture, as well as new methods of design.
Multifunctional Teams

Implementing concurrent engineering requires the use of multifunctional or interdisciplinary teams. Such teams aim to break down the barriers that exist between functional departments in order to promote communication (Lee 1992). Fig. 8 shows how people with different functional specialties, e.g., design, manufacturing, marketing, operation, maintenance, and rehabilitation must work together in a single group. Customers and suppliers are also invited as team members so that real-time feedback can be obtained from them.

The members of such multifunctional teams should ideally have a holistic thinking capability and be able to analyze concepts, fundamental principles, and theories of different disciplines. Team members work together to confront issues rather than to confront each other. To increase the odds of succeeding, it is important that the various team members adopt goals that are product — and market — oriented rather than merely serve as representatives of their particular functions. Lake (1992), quoting Sarchet (1991), said that a team should have accountability for its collective actions and members should develop a feeling of accountability to one another.

It has been determined that interaction among individual members increases the creative and productive process. Hence, the size of a team becomes an important variable to consider. An oversized team creates too many lines of communication and increases overhead costs, while a undersized team is like not having a team at all. Wrong people on a team can also lead to making wrong decisions, thus defeating the purpose of team formation (Carter 1992). When it is not possible to collocate, i.e., bring together team members, computer networks can be used to overcome this problem by virtually collocating various team members.

Concurrent engineering requires that organizations develop new performance-measurement systems, new career-advancement paths, and new reward systems. Members of multifunctional teams should no longer be evaluated with respect to existing individual-performance measures presently prevalent in most organizations. Rather, management should promote the teaming philosophy through the creation of team-performance measures.

A word of caution is warranted here; the implementation of the multifunctional-teaming philosophy within a system that still rewards individual performance has the potential to create more damage than betterment. A perfect example of this scenario is found in the Dallas Cowboys football team. The Cowboys won the “Best Defensive Team” award during the National Football League’s (NFLs) 1992 season. However, none of the defensive players was awarded the distinction of being a member of the Pro-Bowl All-Star Team because nominations to the All-Star team are based on individual accomplishments and not on team performance.

Just like the Pro-Bowl incentive, existing organizational career-advancement paths and reward systems are geared towards individual performance. Management of organizations embracing the concurrent engineering paradigm must devise new career-advancement and reward systems consistent with the multifunctional team concept.

For the success of multifunctional teams, it is important that there be collaboration, and not just communication, between team members. While communication includes the exchanging of information, collaboration means the creation of a shared understanding about the objectives and values of the customer. There are three stages of collaboration that lead a team to a consensus about its role, about solving a problem, and about finding a solution. These stages are to define a common vocabulary, agree on a common purpose, and agree on individual priorities. For a team to succeed, it is of utmost importance that these stages be attained at the very inception of the project. When a team is collaborating rather than just communicating,
it is easier for a team to reach a consensus about a problem and its solutions (Carter 1992).

Organizational Requirements

An organization implementing concurrent engineering concepts is quality oriented and focuses on process consistency, with a sound strategy to characterize each process, its costs, and its value. There is a commitment to understanding the value of the product to the customer. Customer requirements rank first and foremost in the organization’s priorities. To achieve these norms, one or more of the following techniques are frequently utilized:

Total Quality Management (TQM) is a management philosophy that incorporates quality into every step of the product life cycle, by everyone in the company. Its overriding purpose is to increase the value of the product to the customer (Rosenblatt 1991).

Quality Function Deployment (QFD) consists of a pair of spreadsheets that relate customer attributes to quantitative-engineering characteristics. The first spreadsheet shows the relation between the engineering characteristics and the customer attributes. The second spreadsheet shows the relationship among the various engineering characteristics (Rosenblatt 1991).

Just-in-time inventory (JIT) is the philosophy of providing things, information, or materials just when they are needed with the purpose of reducing inventory costs (Rosenblatt 1991).

Statistical Process Control (SPC) seeks to monitor quality in the design and manufacturing stage, starting with a thorough knowledge of the link between defects and the manufacturing process (Rosenblatt 1991).

Design for manufacture and assembly (DFMA) is a philosophy of design that alerts design engineers to the manufacturing implications of their work (Rosenblatt 1991).

An organization implementing the above concepts, in a multifunctional-team environment, will have to overcome the geographical distance between the various team members. A solution to this problem is to link team members through computer-networking technologies in such a way that geographical barriers are overcome. Geographical dispersion of project participants is a major factor defining the role of computers in concurrent engineering.

Role of Computers in Concurrent Engineering

Carter (1992) quotes DeCastro and Hoogerhuis as follows:

The evolving design automation environment that supports concurrent engineering has seen the power and scope of its tools expand steadily. One interesting area is the relationship between advanced-simulation tools and concurrent engineering. As simulation technology grows more comprehensive, designers are approaching the capability to produce ‘virtual prototypes’ that embody all aspects of the product. It will eventually become possible to model the user interface of a product so that customers can interact directly with the virtual prototypes. Their feedback can then be incorporated into QFD maps, which help redirect the design to accommodate their suggestions.

Collocating members of multifunctional teams in a single room is not always possible, feasible, or even practical. Computer networks enable the formation of multifunctional teams with members located anywhere in the planet. Data and information-exchange standards have evolved out of the need for electronic design, engineering, and manufacturing tools, each with its own interface, to communicate data (Carter 1992). Electronic-data standards, which allow computer-based tools to collaborate, cooperate, communicate among themselves and with management systems in a distributed computing environment, are required for an effective implementation of computer-aided concurrent engineering. An emerging standard that promotes the exchange and integration of physical and functional product information over the life cycle of the product is PDES [Product Definition Exchange using STEP (International Standard for the Exchange of Product model data)].

Interoperability between various computers, databases, and user interfaces is a must for the implementation of a successful computer-aided concurrent-engineering philosophy. This can be achieved by a computing environment if tools and databases communicate as part of a common network and the processing power of computers can be shared, the same data is available to all team members involved, and the ways of communicating and manipulating information are consistent for all team members (Carter 1992).

Computer tools for design, analysis, simulation, and visualization linked in a computer network through data and interface standards are ready to enable the practice of concurrent engineering. Tools specifically designed to support the implementation of concurrent engineering are being developed, among other places, at the Concurrent Engineering Research Center (CERC) at Morgantown, West Virginia. CERC was established by Defense Advanced Research Project Agency (DARPA) mainly to help improve the product-development capabilities of the U.S. defense-industrial base. CERC is trying to promote and facilitate the adoption of concurrent-engineering technology in the United States’ industry. An example of the tools being developed at CERC is Meeting On the NETwork (MONET). MONET is a multimedia-conferencing system which facilitates collocation of people and programs in a networked environment. Information exchange with MONET is either passive or active. At present, MONET provides conference facilities; text, audio, and video communication; tools for sharing images on the screen; tools for collaborative sharing of application programs; and cooperative-problem solving (CERC 1992).
CONCURRENT ENGINEERING IN A/E/C INDUSTRY

Knowingly or not, the A/E/C industry has already adopted some elements of the Concurrent Engineering philosophy when it practices TQM, design for constructability, value engineering, computer-integrated construction, design-build contracts, just-in-time-material deliveries and more recently, partnering. Some other elements not yet adopted pertain to the macro-level-multipurpose teams, cooperative and distributed design, true life-cycle analysis of facilities, media for exchanging construction documents, and computer networking.

Concurrent engineering can be implemented in any organization by balancing the following three concepts (Carter 1992).

Organization Structures: The organizational structure should support the development of teams. Teams should operate as a single entity with focus on issues rather than individuals.

Communication Infrastructure: Advances in communications technology are required to link all participants. This will promote the free and speedy exchange of ideas, specifications, and processes. It will also encourage regular feedback from end users.

Product Development: The analysis of the product life cycle should be carried out during the conception and design phases so that no problems are encountered in downstream phases.

Organizational Structure

The A/E/C industry's current macroorganizational philosophy does not foster concurrent engineering. To implement concurrent engineering, the A/E/C industry must switch from the macrofirm functional-organizational structure (Fig. 4) to a macrofirm matrix-organizational structure (Fig. 9). There is a subtle difference in depicting the macrofirm organization to be a matrix type instead of a functional type. Macrofirm-functional organizations allow firms to have a stronger affinity to their functional priorities and foster local optimization. However, this adherence to local-functional priorities sometimes negatively affects the global-project priorities. The matrix organization, on the other hand, indicates that the numerous firms are members of one project team. The players in this macrofirm-matrix organization must carefully find a balance between their project and their functional priorities.

At the individual-firm level, there is no generic organizational structure which is applicable to all firms in the A/E/C industry. Each firm in the industry has its own applicable organizational structure (project, functional, or matrix). Implementing a concurrent engineering philosophy in the A/E/C industry does not require individual firms to adopt one generic organizational structure. Rather, implementing concurrent engineering requires that people in various firms operate in the context of a macrofirm having a matrix-organizational structure.

Communication Infrastructure

Further adoption of the concurrent engineering philosophy in the A/E/C industry involves its paper information-exchange practice. As stated earlier, the A/E/C industry is very fragmented. The firms involved in a single project are typically dispersed both geographically and over time. Computer-networking technologies must be applied to mask the geographical dispersion of the various project participants thus enabling virtual collocation. The industry's wide acceptance of computers gives an opportunity to use electronic-communication technologies. Electronic communication is readily available as evidenced by the numerous electronic mail and electronic bulletin-board systems. Advances in computer technologies such as communication networks, distributed processing, and multimedia conferencing can readily assist in the implementation of concurrent engineering philosophy within organizations ("High-end" 1993).

The switch to electronic-information exchange does not simply involve the linking of the project participants' computers to exchange textual data, such as e-mail messages, or to download files through file-transfer protocols. Several issues such as the exchange of product information among the various incompatible computer tools used by project participants, and the capture, storage, retrieval, and ownership of project-specific information still need to be addressed. The upcoming PDES standard will allow the various incompatible computer tools to exchange graphic as well as product information through the use of a neutral information file format (Reed 1992).

FIG. 9. Partial A/E/C Macrofirm Matrix Organizational Structure
Other changes in the practice of the A/E/C industry include the augmentation of 2D graphical-representation computer tools with 3D-modeling computer tools. 3D modeling offers enhanced visualization benefits for construction operations as well as facility management operations (Reinschmidt et al. 1991). The change from 2D to 3D will have to originate at the designers' offices, otherwise it would make little sense to routinely transform 2D drawings into 3D models in downstream phases.

On the fringes of the communication infrastructures is Virtual Reality Technology. Virtual reality is a computer-generated spatial simulation of reality, also known as the ultimate CAD tool. It is an "inhabitable, alternate environment" created entirely within a computer (Fisher 1990). One can learn about the various features of a facility by immersing in it. One can look in all directions, approach an object that is interesting, feel it, and examine any minute or complex detail (McAvinney 1990). Virtual reality will become a concurrent engineering tool because it can be used by designers in the planning stages to fix problems when it is easier and cheaper (Rheingold 1991). Inexpensive alternatives in designs could be thought of and explored using this tool. Also, the necessity or requirement of a particular design parameter or object could be reconsidered when the design is implemented in the virtual world. Virtual reality can be used in performance evaluation of buildings and to study simulation of various systems in a building such as acoustic, visual, and thermal. Once the initial designs of a building are done, all alterations and/or rectifications can be done in real time on a 3D CAD virtual model. A virtual-world system thus helps A/Es and their clients, contractors, and facility operators explore a proposed building during the design and development phase (Cleveland 1988; Rheingold 1991).

Product Development

Computer-aided concurrent engineering assumes that the majority of the project participants are involved as early as possible in the life cycle of a project and are linked via computer networks. Shifting the contractor-selection basis from low-contract bid to professional qualifications would allow for the timely integration of time-scattered project participants and change the A/E/C industry's lack of interest in research and development. A method of implementing concurrent engineering is to shift from the traditional separate design-construction contractual arrangements to the integrated design-build contractual arrangements (Schroeder 1992).

The present method of involving the various project participants at staggered stages must be changed to allow the inclusion of a majority of these participants during the design phase. Since the concept of design-build is associated primarily with large companies, the A/E/C industry could promote the formation of instantaneous joint ventures between A/Es and general contractors to facilitate a prompt response to owner-driven design-build RFPs. This practice would also foster design-bid-build arrangements whereby facilities' owners procure designs in the traditional method, except that designs must be developed with a pre-defined minimum number of hours of contractor's input. Logically, an A/E firm would form a joint venture with a contractor to produce the design, after which it would submit a bid to build the project.

SUMMARY

Brown (1993), referring to concurrent engineering implementation, said it very simply:

Concurrent engineering has the purpose of increasing the amount of information at decision-making time. It is handled in multiples; referring to multiple aspects of the life-cycle process, multiple people working together, and multiple accumulation of knowledge.

Certainly, nothing the A/E/C can't handle.

Concurrent engineering is a philosophy; hence, its implementation requires only people. To adopt concurrent engineering in the A/E/C industry, though, we need people, computers, and computer networks. In the A/E/C industry, concurrent engineering can bring cost effectiveness and produce nothing less than top quality for the ultimate buyer and consumer of constructed facilities, i.e., owners and end users, respectively.

We close this paper by revisiting the questions posed throughout the paper:

Q: Can concurrent engineering realign the A/E/C industry by overcoming the disadvantages of, while benefiting from, its existing fragmentation and specialization?
A: Yes. Computer networking can make it possible to mask the fragmentation of the A/E/C players by electronically collocating members of multifunctional teams.

Q: How would this macrofirm look within a concurrent engineering paradigm?
A: A macrofirm having a matrix-organizational structure will create an environment whereby the numerous firms would feel as members of one project team.

Q: Can concurrent engineering contribute to the tearing down of the invisible wall between the A/Es and contractors?
A: Yes. A/Es partnering side by side with contractors during the design-bid-build phases are more likely to develop and cultivate respect for each others profession.

Q: Does concurrent engineering offer a philosophy that is conducive to true life-cycle analysis?
A: Yes. By developing multifunctional teams since the conception phase, the views of upstream and downstream participants will be truly considered. Facilities of the highest quality will be the obvious result.

Q: Would concurrent engineering foster an environment whereby small firms could quickly form
joint ventures to effectively respond to design-build request for proposals (RFPs)?
A: Yes. Indeed, joint ventures will even form to respond to traditional design-only RFPs since these can be turned into design-bid-build opportunities.

Q: Does computer-aided concurrent engineering offer an environment for the electronic exchange of project information?
A: Yes. Indeed, proliferation of computer-aided concurrent engineering will accelerate the definition and deployment of badly needed product-definition standards, like PDES. Sustained electronic data interchange among project participants will render paper an undesirable medium for delivering contract documents.

Q: What is the role of computers in supporting the implementation of concurrent engineering?
A: Vital. Without computer technology, concurrent engineering will more likely be practiced only within vertically integrated firms, which are the exception in the A/E/C industry.

APPENDIX. REFERENCES
Concurrent Engineering Research Center at West Virginia University, Brochure, Morgantown, West Virginia, CERC. (1992).