

The New Architect: Keeper of Knowledge and Rules

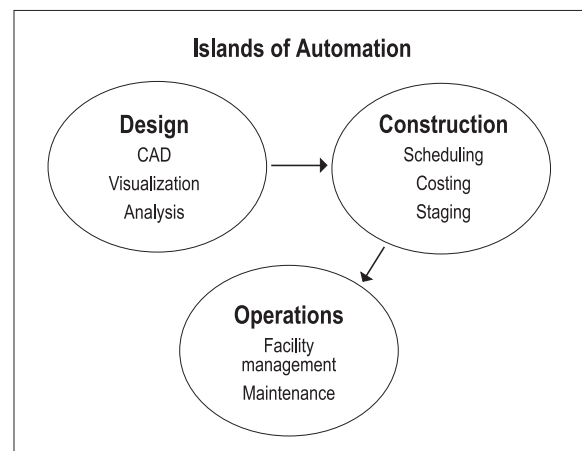
Jonathan Cohen, AIA

Information technology will be a key enabler of process reform in the building industry, historically a laggard in productivity compared to other sectors of the economy. Architects could put themselves at the center of that transformation by harnessing information technology to take on a new role: keeper of project knowledge and rules.

Introduction

Compared to other large industries, the building industry is highly fragmented, with most projects undertaken by temporary, project-based organizations consisting of many small firms. The client may consist of a variety of stakeholders within a company, perhaps including a building committee, groups of end-users and facilities management personnel. The design team may be led by an architect, but will also include subconsultants such as structural, civil and mechanical engineers, lighting designers and many others. And the general contracting or construction management company will use numerous subcontractors and material suppliers in building the work. Communication and the exchange of data between these firms is crucial to the success of any project. Unfortunately, the fractured nature of the building industry is reflected in its' information systems.

In many ways, information technology has made communication within this extended enterprise worse rather than better. Incompatible systems used by individual disciplines create artificial barriers that hadn't existed before. Within the separate domains of design, construction, and operations of buildings, computer tools have been applied to automating specific tasks rather than addressing the overall building process. For example, the design team may use computer-aided design to produce the drawings required for bidding and construction, but these digital work products are not necessarily useful for the tasks performed by the contractor: costing and scheduling. To make matters worse, the proprietary file formats used by most CAD programs can't be read by project management software.



As a result, much exchange of information is still reduced to paper, even when the work is produced on a computer. The floor area of a building, for example, which the architect's CAD program can easily calculate, will often be recalculated and reentered by a construction manager simply because the CAD program cannot easily exchange data with scheduling and estimating programs, which in turn cannot easily exchange data with software for energy analysis or facility management. Whenever these information handoffs occur, the opportunity for delay and error is increased and additional time and effort is needlessly expended in reentering data into new systems.. The building process would be much better served if the entire chain of information from design to construction to operations could remain in one seamless digital format.

The emergence of the Internet in the 1990s offered the possibility of connecting the project team over a network. Networked computing presents the opportunity to integrate information from many sources and then redistribute it to the points of execution where it is needed. Now, the

inability of software programs to talk to each other became an acute liability. Just as a new platform for exchanging digital information cheaply and securely became available, the building industry discovered that it didn't have a common digital language with which to communicate.

A look at current IT tools

Among the most successful applications of the Internet to architectural practice have been the subscription-based, externally hosted extranet or project-specific Web site systems such as Buzzsaw from Autodesk, Constructware from Emerging Solutions, and ProjectNet from Citadon. These systems offer a centralized repository of project documents stored on a Web server, enabling team members to access information from any location. These "application service providers" provide built-in software for viewing and marking up the various kinds of documents used in design and building.

These systems typically include:

- Provisions for security, including authentication of users by means of passwords, and levels of access for different classes of users.
- Centralized electronic document management with version control, issue tracking and time-stamping of specific files accessed by various participants. This enables an audit trail to be kept for each document.
- Provision for displaying files for remote viewing, printing, and markup that does not require the remote user to have the software that created the original file. Autocad drawing sheets, Excel spreadsheets and Word documents can all be viewed and printed from within the Web browser.
- Change notification—alerting users that particular documents have been revised
- Email messaging and group calendar-ing/scheduling, with a system for managing contact information for project participants
- Online conferencing, live chat with white-boarding, and threaded discussion groups

Some architectural firms have created their own project extranet systems, either by installing off-the-shelf software on their own servers, or by adapting open-source project management systems such as Zope. However, one advantage of "hosted" systems is that upgrades can be rolled out to all users simultaneously across project teams.

Whether subscription-based or home made, these systems are effective at refining the existing work process, but they still operate in the world of documents--standalone pieces of information in various formats--and don't address the underlying issue of data exchange between software applications. Several emerging technologies for data exchange promise to fully harness the Internet to transform the design process.

Strategies for Data Exchange

Object-oriented CAD and Parametric 3D Modeling

The term "object-oriented" derives from a computer programming technique in which blocks of code are assembled like Lego pieces into larger components. Object-oriented CAD is a new idea for modeling physical objects such as building components. Elements of a building are represented as *objects*, containing the physical geometry as well as many other kinds of attributes.

Over its first 20 years, CAD was used to automate hand drafting, the creation of 2D drawings such as plans, sections and elevations. Such drawings consisted of lines and shapes without intelligence about what the lines and shapes represented. A CAD program can draw a window with a fine degree of geometric precision, but it does not know about the window's energy efficiency or what it costs or how long it takes to install. The idea behind object-oriented CAD is that rich information about building components could be modeled in a form accessible by a wide variety of software applications and used throughout a building's lifecycle without conversion or translation into other formats. Properties including shape, behavior, performance data, and transport requirements, along with embedded links to relevant code requirements and test results, could all be included in an electronic "object." When an

architect adds a door, it will describe not only the physical attributes of the door needed for design by the CAD program, but also the cost, maintenance, supply and installation properties of the door for use in project costing and scheduling, and later for facilities management.

Objects combine to form a complete model of a building, with much richer information than the three-dimensional computer models used for design study and presentation. Such geometric models include shapes, lines and points, and three-dimensional components such as blocks, cones and spheres, but do not carry intelligence about other properties of these objects. Other kinds of computer models include parametric, procedural, and generative models.

Parametric models permit the relationship between elements to be seen. When a variable is changed, its effect is seen on related elements. Originally developed by the aerospace and automotive industries for designing complex curved forms, parametric modeling works like a numerical spreadsheet. By storing the relationships between the various elements of the design and treating these relationships like mathematical equations, it allows any element of the model to be changed and automatically regenerates the model in much the same way that a spreadsheet automatically recalculates changes in values according to functions embedded in cells. As such, it becomes a 'living' model - one that is constantly responsive to change - offering a degree of flexibility and coordination not previously available. Plans, sections, elevations, finish and door schedules are all generated as views of the model and automatically updated with every change.

Models and Metaphors

The computer industry likes to use metaphors to describe concepts. Sometimes the metaphorical use becomes so widespread that it supersedes the original term. Many architects have noticed how many terms have been borrowed from "our" vocabulary—site, user, program, and of course, the term architecture itself. Sometimes the result—as with the term *model*—is confusion between metaphors and the real-world concepts to which we think they refer.

A physical model, such as those architects make out of wood and plastic, is easy to understand but limited in its use. It must be physically transported from place to place. But it is a powerful representational tool because it is intuitively grasped and highly interactive. People can move around it and select any view from which to experience it, making it a very seductive form of presentation, as architects have known for centuries. A computer model is another kind of model. It lacks the charm of a physical model but compensates with versatility, ease of revision, and portability.

The discussion about shared project models as a new paradigm for describing buildings refers to models that embody three-dimensional geometric information, but also information about the attributes of the object being modeled, such as what it is made of, who makes it, what it costs, how long it lasts, or how many worker hours are needed to install it. The shared project model is not necessarily a literal model at all, but a kind of database. It is sometimes referred to as four- or even five-dimensional CAD, where the three physical dimensions are augmented by time and cost.

Industry Foundation Classes

In order for object-oriented CAD to reach its potential for enabling collaboration and data sharing, it is important that it be built on agreed, open standards rather than proprietary technology. The development of such standards is the mission of the International Alliance for Interoperability (IAI.) IAI is a consortium founded in 1995 to develop methods for sharing information during design and construction and throughout the life-cycle of buildings. Its members include architects,

engineers, client organizations, product manufacturers, and software companies. IAI is defining *industry foundation classes* (IFCs), a technology for modeling building elements that enables project information to be shared by the different kinds of software applications in use in the industry. When an architect adds a window, the window *class* will describe not only the geometric attributes of the window needed for design by the CAD program, but also the cost, U-value, finish, and installation properties of the window for use in project costing, scheduling, energy analysis, and, later, for facilities management. By examining the design process within each discipline, IAI plans to define the information that each particular practitioner requires to do his job.

The assumption of IAI is that the various participants in the AEC process will continue to use their own discipline-specific software tools, but by making these tools IFC-compliant they will be able to exchange information easily. A database of IFCs would define the entire building project, and would continue to evolve during the design, construction and operations phases. The practicality of such an approach has been demonstrated in the BLIS project (Building Lifecycle Interoperable Software) in which models created in architectural design software have been handed off to software for energy analysis, code checking, cost estimating, and construction planning and then passed back to the architect and reopened in the original software.

While IFCs define a complete project model, there is also a need to export data from the model so that specified products can be matched up with manufacturer's data, for example. For that, a new Web language is needed.

XML

Architects search the Web for product information, code and building type research, and many other things. But searching the Web is often frustrating, because Web pages written in the standard HTML language do not describe their content to search engines. A new Web language, Extensible Markup Language, or XML, will make searching for specific content much easier, with wide-ranging implications for business-to-business

communication such as occurs in every building project.

While HTML describes how data should be presented, XML describes the data itself. A number of industries and scientific disciplines—medical records and newspaper publishing among them—are already using XML to exchange information between companies using previously incompatible software. Trading partners can invent their own *schema*, or XML language, for their private use or entire industries can agree on standards. XML can be tailored to describe virtually any kind of information in a form that the recipient can use in a variety of ways. XML tags can identify every attribute of products and building components, from bending strength to reflectivity. It is specifically designed to support information exchange between systems that use fundamentally different forms of data representation, as for example between CAD and scheduling applications.

For any language to function, there must be agreement on the precise meaning of terms. The success of XML hinges on finding away to standardize terminology used in an industry. At present, different players within the AEC industry use the same term in different ways. For example, a door can be, depending on context: (1) an opening in a wall; (2) an assembly consisting of a frame, a leaf, and hardware; (3) a scheduling item; (4) a cost item; (5) a product to be manufactured and delivered; or (6) a building asset to be tracked and managed. An industry-specific implementation of XML will need to be precise enough to clarify these different usages and be flexible enough to grow over time.

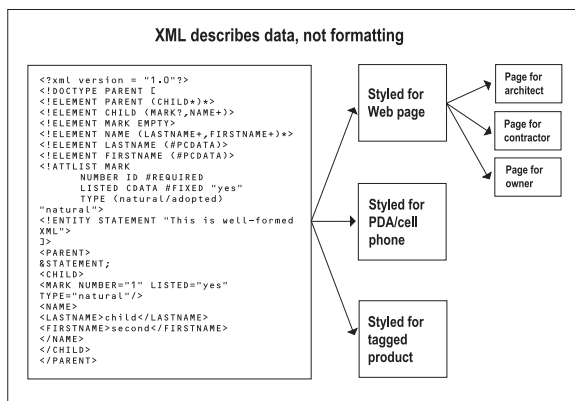
In 1999, a working group, since folded into IAI, began developing an XML language for the building industry, called aecXML. A parallel effort in the UK has produced PISCES, an XML language for the lifecycle of real estate assets.

When XML is used to write project specifications, a contractor will be able to extract both quantitative and qualitative data and match it with information from manufacturers' product data. A manufacturer will be able to scan a set of contract documents and match specified items with items in its own catalog, take an order, and move it into production and delivery. Once that product arrives at a job site, carrying the same XML code written by the original specifier, a construction

worker using a scanner and handheld computer will enter it into the master schedule for the project.

XML can be used to describe virtually all the objects, documents, services, and organizations needed to complete a project. Because data about these attributes is divorced from the program used to create it, information is no longer imprisoned by file types and software incompatibility. Because richer information can be described in XML than with HTML, Internet searches will be far more accurate than they are at present. Users can filter information, extracting only the specific data needed, or create collapsing and expanding views of the data on demand. The implications for Web-based operation manuals, equipment schedules, and the like are enormous. A maintenance engineer, for example, could easily extract only the specific information needed to service a building component from a mass of data that would otherwise be overwhelmingly complex.

XML will allow users to access different aspects of a single database and display them in a customized way.



XML documents could contain information that would be visible to some users and invisible to others. The project file is now completely divorced from any paper representation of it; an unlimited variety of context-based views of the same information is now possible. The very notion of discrete types of standalone documents—plans, specifications, correspondence, schedules—would become obsolete.

Properties including shape, behavior, performance data, and transport requirements, along with embedded links to relevant code requirements and test results, could all be included in an

electronic specification. Architects would be able to compare price and performance of various models, check available finishes, or study the energy consumption of a product when used in a particular sun exposure. Instead of serving as a static single-use document, a product specification could actually “learn,” not only during the design and construction process but over the lifecycle of all buildings known to contain the product. Performance issues, maintenance, and replacement data could all be integrated into such a “living” specification.

The Shared Project Model

Data exchange standards such as XML and IFCs, combined with parametric 3-D modeling and the Internet, form the basis of a shared project model (sometimes called a building information model or virtual building model) which would replace individual paper or electronic documents with a single knowledge base describing an entire project. Participants would have real-time access to the model throughout the life of the project, in turns contributing their own knowledge and using information contributed by others. Each discipline that a project team comprises would continue to use specialized tools for performing its own aspect of the work, but these tools would have the ability to draw from and contribute to, a common pool of information within the context of an intelligent information system that does not require reentry or translation of information once it has been created.

Objects within a building model carry with them dimensional data, as CAD objects do, but also specifications, code and performance data, cost, and information related to construction means, methods, and scheduling. An object representing a steel beam for example would be drawn, first, *architecturally*, with its physical characteristics; second, *structurally*, with its load-bearing properties; third, as a *cost item*; fourth, as a *scheduled process* of fabrication and delivery, and so on. Each participant would draw on the common object to access the information and manipulate it with discipline-specific software. An architect would draw and model, an engineer would calculate, and a construction manager would schedule, all using information from a common project database that is accessible over a network. Architects would con-

tribute the physical design attributes of a building to the larger computer representation of the building as both an object and a process. The shared project model becomes almost a living organism that can be accessed asynchronously by its many contributors. Information is now available in context-specific forms, rather than inflexible paper-based presentation formats. Teams could have multiple “live versions” of a project available simultaneously to fully support design collaboration.

This kind of team-shared, Internet-accessible single model approach is already widely used in the aerospace and automobile industries, where it is known by the term *product lifecycle integration*.

Implications for the Building Industry

The shared building model and the Internet offer the prospect of significant productivity and efficiency improvement in the building industry—but only if accompanied by significant process reform. At present no one—owner, designer, or builder—takes the enterprise-level view of the entire building process, and this presents an historic opportunity for the architectural profession.

Industries such as aerospace and auto manufacturing, shipbuilding, and process plant engineering have used enterprise-wide information technology to fundamentally change their ways of doing business. Product lifecycle integration has enabled design, production, and operations to be informed by each other in a kind of feedback loop. Results have included:

- shorter product cycle time from concept to market
- less waste with lean processes
- more choice for the consumer with mass customization
- higher quality at lower cost

At the same time, Internet-based communication technology has enabled decentralization of organizations by making information accessible to geographically distributed work teams and supply chains. Companies such as Nike demonstrate how large enterprises can successfully outsource all production while concentrating on design, marketing, and coordination. The trend toward decen-

tralization and outsourcing suggests that there may be new ways of organizing work that would improve efficiency in the building industry without changing its traditional reliance on small firms. By making external communication cheap and secure, the Internet changes the equation, offering the possibility of connecting the various players in a building project within a networked, or virtual organization.

The Evolution of Enterprise Computing		
Mainframe Systems <ul style="list-style-type: none"> • Limited access to information • 10s–100s of users 	Enterprise Systems <ul style="list-style-type: none"> • Client-server networks • Centralized organizations • 100s–1,000s of users 	Distributed Web Systems <ul style="list-style-type: none"> • Peer-to-peer networks • Empowerment of employees and customers • Connecting the team (partners and suppliers) • Networked organizations • 1,000s–unlimited users
1960–1980s	Late 1980s–1990s	Late 1990s

Networks of small, independent, but tightly integrated firms each contributing to a cooperative process and supported by enhanced communication, may be a better fit to the AEC industry than either the compartmentalized design-bid-build system or the vertically integrated industrial model used by design-build companies. Such a flexible alliance of specialized firms, which come together for projects, disband, and then re-form, can be effective if supported by an ability to capture, store, and reuse crucial knowledge and standards. Quality and innovation are enhanced because each member of the networked organization contributes its specialized expertise, which adds to an ever-expanding knowledge base to the benefit of all.

Who will be in charge of this more rational design and building process? Clearly, the one who sets standards and controls the project information will be at the center of the building team. This “project information architect” may combine characteristics now associated with architect, quantity surveyor, process engineer, and construction manager. The duties of this new kind of architect would encompass a comprehensive overview of projects throughout a process that extends from site selection and programming through facilities management.

The project information architect is the:

- Designer, not just of buildings but of the building process
- Keeper of knowledge and rules—the one who selects, filters, classifies and maintains information within the project team and from project to project
- Maintainer of standards and quality assurance
- Coordinator of specialists
- Builder of a community of interest around each project

The project information architect would be at the center of a flexible, networked organization, a temporary grouping of physically dispersed, independent companies. Such a virtual organization would be founded on trust—a willingness of participants to share goals, risks, and information while retaining their own individual ownership.

Highly successful models of networked organizations have existed in other industries for many years. Movie production in Hollywood is one example. Until shortly after World War II, movies were made under a studio system in which a few vertically integrated large companies controlled every aspect of production, distribution and display of films. When this system collapsed under antitrust pressure in the 1950s, movie production shifted to teams assembled on a project-by-project basis and that is still the norm today. The studios continued to control the financing, marketing and distribution of films, but film production became a project-based virtual enterprise. The transformation from industrial-style to networked organization took place in just a few years.

Today, movie production is an agile industry in which projects go from idea to production in weeks. There is high reliance on trust and standards. When a project gets the green light, hundreds of small firms and individuals quickly get up to speed. Most participants get a “piece of the action” in addition to salaries and are contracted with simple letters of agreement. Powerful talent agencies are the equivalent of project information managers, brokering deals by assembling specialist teams—actors, directors, writers, and technicians—and packaging them for investors and financiers.

The Italian textile industry clustered around Prato in Tuscany is another example of a decentralized, networked organization. In the early 1970s, the large and failing Mannechetti textile firm broke itself up into small, autonomous units each specializing in one of the steps in the design and production process. Other large mills did the same thing. By 1990, Prato was home to thousands of small design and manufacturing shops, nearly half of which employ fewer than 10 people. The firms pooled their research and development efforts, and with the support of the Italian government, made large investments in CAD/CAM and networking technology, and flourished as quality and innovation soared. In a few years, Prato became the most important cluster of fabric design and manufacturing in Europe, tripling its profits during a time when the overall European textile industry was in decline. In the same way that Hollywood talent agencies assumed the role of broker and deal-maker, a new kind of “infomediary” appeared in Prato—the *impannatore*. These independent agents provide the crucial coordination services for design and production of fabrics, putting together temporary teams of small firms to fulfill the particular requirements of each customer.

The culture of networked organizations is based on cooperation and trust rather than hierarchical command-and-control. Entrepreneurial small businesses are free to innovate, and these innovations are diffused throughout the enterprise. In this environment, standards—accepted ways of doing things—become ever more important, enabling specialists who have never worked together to quickly become productive with each other, in the same way that makeshift surgical teams of doctors and nurses are able to work effectively in emergencies, using well-defined protocols and procedures.

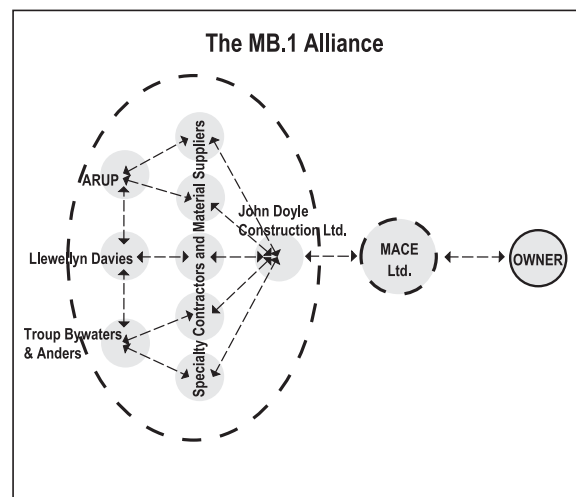
Attributes of traditional versus virtual organizations:	
Traditional "Fordism"	Virtual
<ul style="list-style-type: none"> ▪ Scale ▪ Mass Production ▪ Hierarchy ▪ Command and Control ▪ Large companies, vertically integrated 	<ul style="list-style-type: none"> ▪ Flexibility ▪ Customized Production ▪ Informal Network ▪ Cooperation, trust ▪ Small but connected companies focused on core competencies

By allowing small companies to concentrate on what they do best, networked organizations foster innovation and responsiveness to customer requirements. Such organizations are supported by distributed knowledge bases, which makes enterprise-wide data accessible to anyone with a Web browser. When information can be shared instantly and inexpensively across dispersed project teams, the need for centralized bureaucracies and large fixed overheads is greatly reduced. And networked organizations can have strong brands as Nike and Nokia have proven. Behind the brand, the inner workings of such organizations is invisible to the client.

Although this organizational model seems a perfect fit for the building industry, there are a number of deeply ingrained cultural inhibitors will have to be overcome in order for it to gain acceptance:

- At present, no one "owns" the whole building process. The traditional insularity of the design professions from the construction process mitigates against an industry-wide focus on the customer and product.
- Inequitable sharing of risk and reward: there are few incentives for designers and builders to innovate and sometimes there are severe risks in doing so.
- Investment in research and development is weak and not centrally directed and shared to benefit the entire building industry.
- A widely held belief that the building industry is so unique that little can be learned from innovations in other industries.
- Legal and insurance boundaries have been so tightly drawn that they inhibit experimentation in process delivery models.

In some countries there has been greater willingness to reengineer the design and construction process. In England, the management consultancy MACE Limited has applied the networked organization model to the building industry. MACE created an alliance of 16 firms—designers, contractors, material suppliers—that provides one source design/build services to office building developers. MACE discovered that these clients all wanted the same things: predictable cost, on-time delivery, and quality, and they wanted them faster than the traditional process could provide. These demands could only be satisfied by controlling the entire process, but not with a vertically integrated design/build company. An alliance of independent firms, if they put their goals and methods into alignment, could do the job with more flexibility to the specific requirements of each project.



MACE's sole-source contract with the owner is passed through to all the members of the alliance, who share in the risks and rewards while maintaining their individual identities. This alignment of goals allows the team to freely share information and create work processes that benefit the project overall, for example by involving mechanical and electrical subcontractors early in the design. This kind of collaboration is enabled by the strategic application of networked computing to capture, store, use, and reuse critical project knowledge and standards.

For More Information

For more on the impact of the Internet on architecture and the building industry, see *Communication and Design with the Internet, a Guide for Architects, Planners, and Building Professionals*, by Jonathan Cohen, (WW Norton, 2000.)

For a comprehensive treatise on the networked economy read *The Rise of the Network Society* by Manuel Castells (Blackwell Publishers, 1996.)

For more on the IAI, IFCs, BLIS, and XML, visit the IAI North America Web site at <http://www.iai-na.org>. Groundbreaking work on design-construction integration has been done by Stanford's Center for Integrated Facilities Engineering (<http://www.stanford.edu/group/CIFE>.)

For more on networked organizations, see Sproull, L. and Kiesler, S., *Connections: New Ways of Working in the Networked Organization*. (The MIT Press, 1991.)

MIT economist Thomas M. Malone has written extensively about virtual organizations:

Malone, Thomas W., Robert J. Laubacher, and the MIT Scenario Working Group, "Two Scenarios for 21st Century Organizations: Shifting Networks of Small Firms or All-Encompassing 'Virtual Countries?'" MIT Initiative on Inventing the Organizations of the 21st Century Working Paper 21C WP #001 January 1997

Malone, Thomas W. and Robert J. Laubacher, "The Dawn of the E-Lance Economy," in *Harvard Business Review*, September-October 1998

Malone, Thomas W. et al, "What do we really want? A manifesto for the organizations of the 21st Century," The MIT 21st Century Manifesto Working Group, MIT Initiative on Inventing the Organizations of the 21st Century Discussion Paper, November 1999.

For a fascinating discussion of the movie business as a virtual enterprise, see DeFillippi, Robert I. and Michael B. Arthur, "Paradox in Project-Based Enterprise: The Case of Film Making,"

California Management Review 40/2 (Winter 1998): 125-139.

For more information about MACE and its design-build alliance, see Martyn Day and Randall Newton's article "Mace and the MB1 Alliance—How a Major UK Construction Management Firm Organized a Virtual Design/Build Consortium" in *A-E-C Automation Newsletter*, October/November 2001, which can found online at <http://www.aecnews.com/reprints-pdf/pdf/Nov01Mace.html>