Healing a Fragmented Industry: New Opportunities for the Architectural Profession

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New construction and renovation account for roughly one tenth of the U.S. gross national product and directly employ nearly 6 million people. Worldwide spending on construction exceeds $4.5 trillion dollars annually, around $500 billion in the United States alone. AEC is a huge industry, yet it is in many ways the opposite of an industrial process. Its products are unique prototypes built in place one at a time. The economies of scale that apply to mass production cannot be realized in building. It simply is not economical to spend the same kind of resources designing and constructing a single building as are spent designing a product that may be manufactured thousands or millions of times.

Compared to manufacturing, the AEC industry is highly fragmented. Each project is a one-time collaboration of many organizations—owner, designer, builder, subcontractor, material supplier. The industry is characterized by small companies and by significant levels of outsourcing by both design and construction firms. Relatively small firms have historically served local, rather than national, markets. The largest construction companies have tiny market shares compared to their counterparts in manufacturing industries. Turner Corporation, the largest general contractor in the U.S., ranks a lowly 375 in the Fortune 500, and most AEC firms are far smaller than that.

Construction is also highly cyclical relative to the overall economy, increasing risks and keeping organizations small. Construction firms tend to be undercapitalized and to operate with low overheads relative to the size of projects undertaken. Insurance and financing mechanisms, such as performance bonds, have evolved to spread the risk.

Industry-wide standardization of means and methods is almost nonexistent and the organizations that purport to speak for the industry are themselves fragmented and weak. Most of the innovations that do occur are focused on construction materials and techniques, not the product delivery process. Innovations tend to be closely held by companies and are not disseminated throughout the industry. Because design and construction functions tend to be highly compartmentalized, the innovations that might flow from interdisciplinary synergy are suppressed. Competition in construction is often reduced to price alone, rather than value, in part because the very fragmentation of the industry has made value difficult to measure.

Remarkably little is spent on research and development, less than 0.5 percent of annual revenue, compared to 3.7 percent in manufacturing. There is also a low rate of spending on education and training, particularly for the rank-and-file workforce and lower levels of management. But increasingly, building is about managing information as much as managing goods and services. Just as it occurred in agriculture and mining, the construction industry will inevitably transition from a low-skill, high labor industry to a knowledge-added endeavor requiring a higher level of investment in training, technology and business process engineering

In manufacturing CAD/CAM integration has resulted in productivity gains that the construction industry can only dream about. Product design and manufacturing have been fully integrated—one informs the other. General Motors, for example, routinely involves suppliers in parts design. Boeing is able to digitally preassemble whole aircraft, then share pieces of the model with component subcontractors.

In modern manufacturing the entire relationship between design and production has been turned upside down. Results have included shorter product cycles, less time to market, more choice for customers, and real competition based on product value. Designers do not simply create products that are functional and attractive; their designs must consider efficient fabrication and maintenance as well. Increasingly, manufacturers are able to respond to the smallest change in market demand and customer preferences. The key to the feedback loop between design and production has been information technology, the ability of manufacturers to gather information from the production line and from customers and suppliers and then incorporate it into the design process.

In contrast, it is sadly the case that builders and designers rarely evaluate even their own products through post-occupancy review and data collection. The feedback loop between design and production that is so valuable to manufacturers does not occur in construction. Post-occupancy evaluation, if it is done at all, is too often first undertaken by experts building a case in litigation. That's a shame, because many lessons learned in completed buildings could be applied to the next design. Scholars have long talked about "buildings that learn" structures that evaluate themselves and feed back information to inform the design process, but little has been done in practice to bring this about. For now, this kind of vital information is lost.

Evaluation can become an integral part of the design process, but only with significant change in the industry. Better project monitoring and information flow require closing the loop of design—construct—inhabit/operate—evaluate—design, making it a circular process rather than the traditional linear one. The industry must shift to a process that incorporates lifecycle-based decisions all the way from initial programming and site selection through to the eventual retirement of the building. This can only occur when the flow of information throughout the building process has been integrated.

The industry's fragmentation derives in part from the historic separation of design and construction that evolved over the course of the last 150 years. All design work became the domain of professionals, and those further downstream in the process—the contractor and product manufacturer—were largely excluded. In this model, production has little opportunity to inform design early enough in the process for it to be effective.

The strict division between design and construction functions began to break down as building systems became increasingly complex. After World War II, the percentage of the total work devoted to electrical and mechanical systems began to increase sharply. All the performance specifications, design/build subcontracting, shop drawings and material samples, mock-ups, and laboratory tests that a typical project generates testify to a design and construction process that is in fact quite interwoven. The lines drawn between design and production have blurred so much that the distinction may already be obsolete.

ISLANDS OF AUTOMATION

The amount of information generated in construction projects is huge—yet communication among the participants is disjointed. It has been estimated that a staggering thirty percent of the cost of buildings is lost due to poor communication within the industry.

The first applications of information technology to the design and construction process made the completion of individual tasks easier: drawing a set of construction documents, preparing a specification, creating a CPM chart. They did nothing to integrate the overall process or to make it easier for the various participants to coordinate their activities; they did not do a good job of interoperating with each other. Integration was now even more difficult, because incompatible systems used by individual disciplines created artificial barriers that hadn't existed before.

The subsequent, more profound application of information technology is signaled by the arrival of a networked model of computing. Networked computing presents the opportunity to reform the entire process of creating the built environment. It can do this by integrating information from many sources and then redistributing it to the many decentralized points of execution where it is needed. This second wave of information technology in design and construction, if it is properly deployed, should revolutionize the industry.

In a typical design process, each discipline constructs its own "model" of the building and represents its understanding of that model using symbols and representational aids that are unique to that discipline. These symbols are laboriously translated into formats that other disciplines can use. They are often imperfectly understood by other members of the design team, including those responsible for overall coordination, typically the architect. For the most part, design information remains within "knowledge domains," behind walls of jargon, symbolism and incompatible means of representation.

Most document formats are still based on historical paper equivalents, using standard drawing sets and paper sizes. When information is handed off from one participant to another, it is usually in the form of an exchange of printed paper documents, even though the information was created on a computer. So the printed page remains the only common interface between all the discipline-specific computer applications. Software companies have contributed mightily to this problem by locking in their customers to proprietary, mutually exclusive file formats that compound the difficulty of collaboration.

Rationalization of the construction industry is likely to mean major organizational and contractual changes for both designers and builders. A full team approach is called for, with budget, project scope and scheduling considered in earliest design. Allowing project information to flow from designer to estimator to builder to owner and back again should be the goal. It will mean moving the involvement of builders forward in the process to capture their expertise in costing and constructability. And it will mean giving designers a meaningful role later in the process, so that they can apply lessons learned in building and operating facilities. They key to this integration will be the effective deployment of information technology to capture, store and reuse vital project information.

In 1996 the National Science and Technology Council established seven national construction goals, which included a 50 percent reduction in delivery time, a 50 percent reduction in operations, maintenance and energy costs, and a 30 percent increase in productivity (output per work hour). At a workshop on how to achieve these goals held in 1996 by the National Institute of Building Sciences (NIBS), forty one organizations representing builders, designers, and property owners concluded that the major obstacles were "in the process—a process that starts with the need for a timely decision to begin and continues through site selection, community involvement, zoning approval, regulatory clearance, design, plan reviews, permits, construction, commissioning, operation, maintenance, renovation, and ultimately, demolition."

So far, the main industry response has been to promote design/build contracting, eliminating the architect as an independent entity. Design/build puts design and construction functions under a single contract and changes the historical relationship of parties. Architects are threatened by a loss of independence in design/build, as well as a perceived deemphasis on aesthetics and subjective criteria. Many also feel that owners do not appreciate the inherent conflict of interest in having the architect employed by or in partnership with the contractor.

But design/build is gathering steam. The Department of Commerce predicts that by 2001, sole-source design/build firms will be responsible for over 50 percent of U.S. construction projects, up from only 10 percent ten years ago. This trend is extending into public-sector contracting as well. In many states, laws that forbade sole-source public contracting are being repealed, and some federal agencies are moving toward design/build as well. The perceived advantages of design/build for the owner go beyond a compressed project schedule and one source of responsibility. The design/build entity is held to strict liability for defects in construction; there is no "standard of care" provision protecting the designer, and therefore the warranty is stronger. Some design/build contracts contain performance warranties for the entire project, even covering consequential damages such as lost profit. Such contracts make projects easier to finance by ensuring that the owner will have an uninterrupted revenue stream with which to pay back the loan.

But design/build is a regression to a vertically integrated industrial style of organization—exactly what manufacturers worldwide are moving away from. By making external communication cheap and secure, the Internet is changing the equation, offering the possibility of connecting the various players in a building project with a networked organization.

NETWORKED ORGANIZATIONS AND THE PROJECT INFORMATION MANAGER

A network 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 situation of the AEC industry than the rigidly compartmentalized organization that is in place now, or the outmoded industrial model presented by design/build. Such a flexible alliance of specialized firms, which come together for projects, disband and then re-form again, can be highly innovative and effective, if supported by an ability to capture, store, use, and reuse crucial project information. Quality and innovation are enhanced because each member of the networked organization contributes specialized expertise, which becomes part of an ever-expanding knowledge base to the benefit of all.

A new process is needed for sharing information, not only during a project but from project to project. Well-documented project histories can be the foundation for programming and budgeting the next project. Stakeholder participation can begin much earlier and take a more important role in the design process. Collective memory can supplant individual experience. But none of this is part of traditional architectural or construction management services. Clearly, the one who controls the project information will be the most powerful, irreplaceable member of the building team. Will it be the architect, the construction manager, or someone new?

The role of project information manager (PIM) may combine characteristics now associated with architect, quantity surveyor, and construction manager. The duties of a PIM encompass a comprehensive overview of a project, not just as one snapshot in time but throughout a process that extends from site selection and programming through facilities management. It is a natural extension of an architect's traditional persona as the generalist, the professional who can maintain an overarching vision of a project while drawing from specialists the many kinds of expertise needed to create it.

What services might the project information manager provide?

- Building process designer
- Interface designer
- Information intermediary—the one who selects, filters, classifies and maintains information
- Maintainer of standards and quality assurance
- Coordinator of specialists

Keeper of the knowledge base, now broadly defined to include virtually every factor a building project must contend with during its life: the building program, the economic and political inputs, climatological and anthropometric data, the intellectual and artistic milieu, as well as the products, systems and techniques of building

The project information manager would be at the center of a flexible, networked organization, a temporary grouping of physically dispersed, independent companies. Such a virtual organization would be characterized by trust—a willingness of participants to share goals, risks, and information. The culture of networked organizations is founded on information sharing rather than hierarchical command-and-control. Entrepreneurial small business units are free to innovate, and these innovations are diffused throughout the enterprise.

Successful models of such networked organizations already exist. The Hollywood film industry, for example, is in some ways an interesting analogue to AEC. 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 exhibition of films. When this system collapsed under antitrust pressure in the 1950s, movies began to be made by teams assembled on a project basis. The transformation from industrial-style to networked organization took place in just a few years.

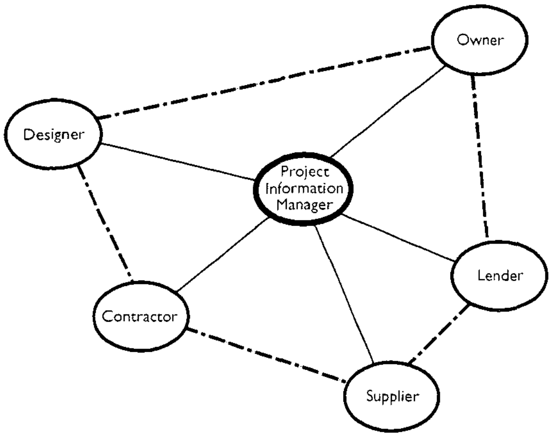
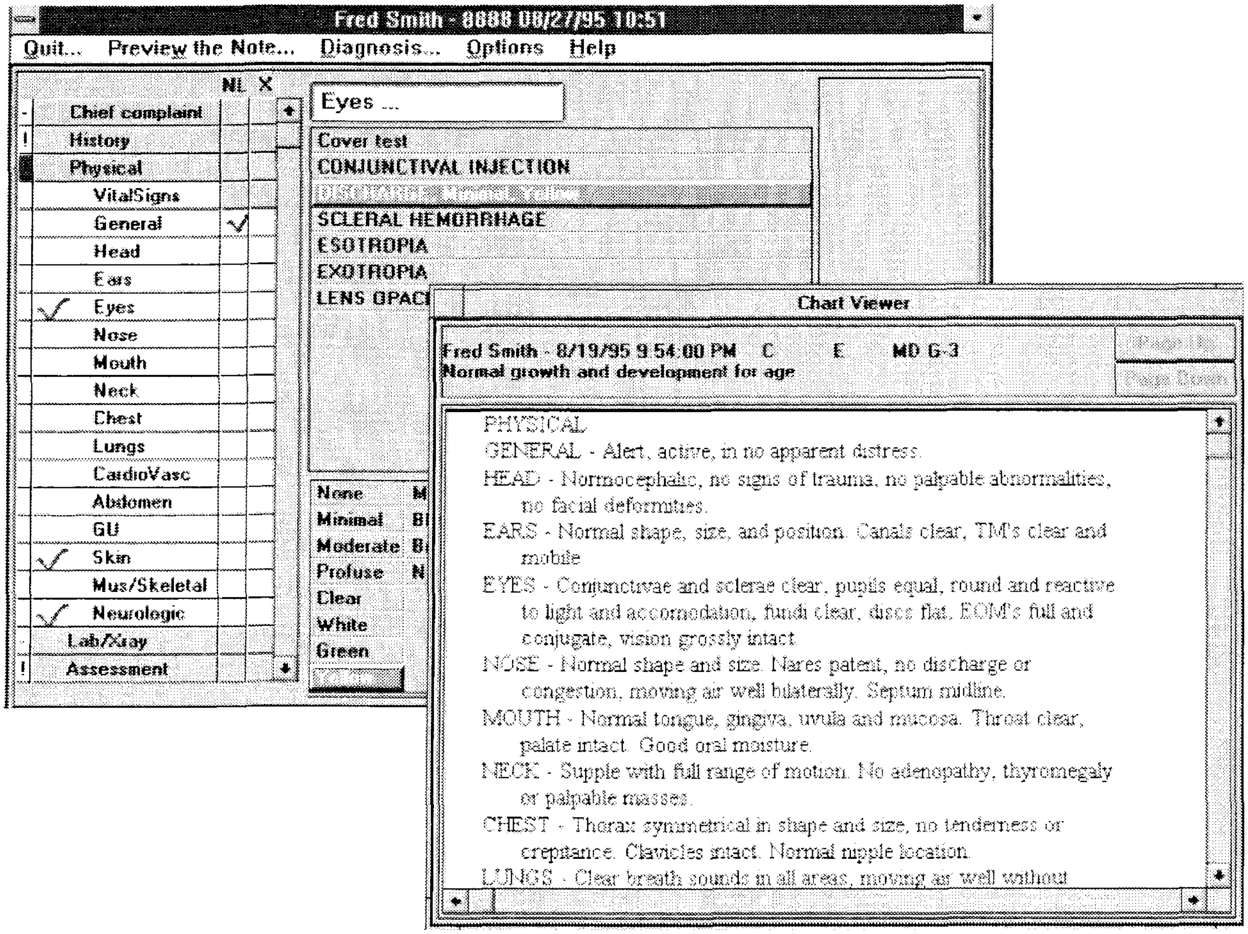


Fig. 1: The Project information manger is a the the center of the networked AEC organization.

Powerful talent agencies became the equivalent of a project information manager, brokering deals by assembling specialist teams—actors, directors, writers, and technicians—and packaging them for investors and financiers.

Another highly successful example of a networked organization can be found in the textile mills of Prato in northern Italy. Beginning in the early 1970s, several large (and failing) textile firms were broken up into small, autonomous units specializing in one or a few steps of the production process. By 1990, Prato was home to over 15,000 small manufacturing shops, averaging fewer than five employees each. The firms pooled their research and development efforts, made large investments in CAD/CAM technology, and flourished as quality and innovation soared. Prato became the most important cluster of fabric design and manufacturing in Europe, with annual revenues of $4.5 billion. 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



Fred Smith - 8/19/95 9:54:00 PM C E MD G-3
Normal growth and development for age

PHYSICAL
GENERAL - Alert, active, in no apparent distress.
HEAD - Normocephalic, no signs of trauma, no palpable abnormalities, no facial deformities.
EARS - Normal shape, size, and position. Canals clear, TM's clear and mobile
EYES - Conjunctivae and sclerae clear, pupils equal, round and reactive to light and accomodation, fundi clear, discs flat. EOM's full and conjugate, vision grossly intact.
NOSE - Normal shape and size. Nares patent, no discharge or congestion, moving air well bilaterally. Septum midline.
MOUTH - Normal tongue, gingiva, uvula and mucosa. Throat clear, palate intact. Good oral moisture.
NECK - Supple with full range of motion. No adenopathy, thyromegaly or palpable masses.
CHEST - Thorax symmetrical in shape and size, no tenderness or crepitance. Clavicles intact. Normal nipple location.
LUNGS - Clear breath sounds in all areas, moving air well without

Fig. 2: XML is already in use in many industries; shown here are medical records written in XML for interpretaton by a wide range of applications.

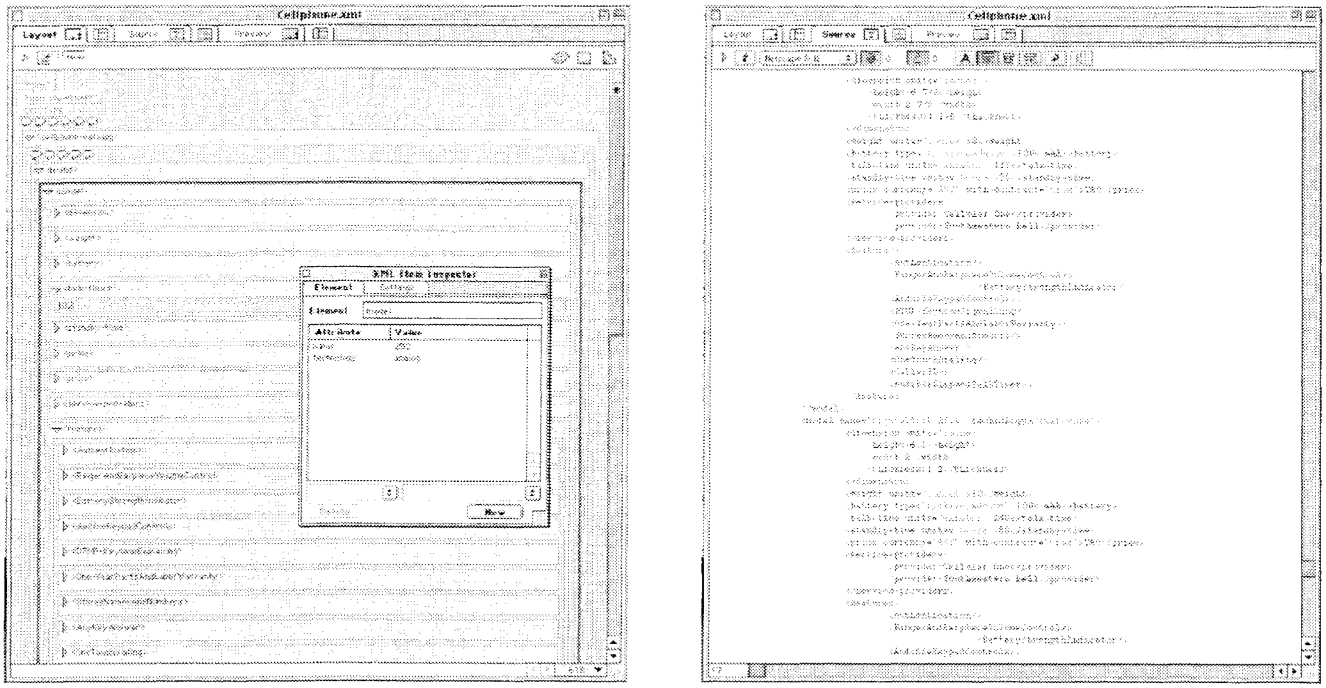


Fig. 3: XML permits nesting of tags, making it ideal for specifications and product descriptions.

temporary teams of small firms to fulfill the particular requirements of each customer.

Perhaps the finest example of a networked organization is the Internet itself, which, after the first seeds were planted by the government, grew rapidly as a self-governing, cooperative organization without central control. By allowing specialist companies to concentrate on core competencies, networked organizations make better use of management resources and allow innovation and close customer relationships to flourish. When information can be shared instantly and inexpensively across geographically dispersed project teams, the need for centralized bureaucracies and large fixed overheads decreases. In this environment, standards—accepted ways of doing things—become ever more important, enabling teams of specialists who have never worked together to quickly become productive. Consider the way that hastily-assembled surgical teams of doctors and nurses are able to work effectively in emergencies, using well-defined protocols and procedures.

OBJECT-ORIENTED CAD AND XML: THE FUTURE OF THE WEB?

Two emerging technologies—object-oriented CAD and XML—promise to be the enablers of a more integrated design and construction process within a networked organization. Object-oriented CAD is an entirely new paradigm for modeling physical objects. At present, CAD files carry little more information than the pencil drawings they replaced. A CAD program can draw a window, for example, with an exquisite degree of geometric precision, but it cannot write a specification for the window or add the window to the manufacturer's order book or schedule the window's delivery and installation, or supply its U-value or the expected life of its painted finish. 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." For example, when an architect adds a door, the door *object* 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.

The second key enabler is a new kind of language for describing information—*Extensible Markup Language* (XML).

A number of industries and scientific disciplines—medical records and newspaper publishing among them—are already using XML to exchange information across platforms and applications. XML can be tailored to describe virtually any kind of information in a form that the recipient of the information can use in a variety of ways. 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.

The success of XML to enable the kind of open information sharing that is needed to integrate the building process hinges on finding a way to standardize AEC terminology. For any language to function, there must be agreement on the precise meaning of terms. Semantic integrity means that words used should mean the same to the sender as they do to the receiver. Traditional means of achieving this aim with human languages have included dictionaries and glossaries. If computers are to exchange information with each other without active human intervention, however, a much higher degree of precision is needed.

At present, different players within the AEC industry use the same term in somewhat different ways. For example, a *door* can be, depending on context, either 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 with changes over time.

If XML is widely adopted, it will enable data sharing and electronic commerce in the building industry on a scale not previously imagined. When XML is used to write project specifications, for example, a contractor will be able to extract both quantitative and qualitative data and match it with information from manufacturers' and subcontractors' Web sites. 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 hand-held computer will enter it into the master schedule for the project.

XML tags can identify every attribute of products and building components, from bending strength to reflectivity. In fact, XML could be used to describe virtually all the objects, documents, services and organizations needed to complete a project. Because data about these attributes would be divorced from the application used to create it, information would no longer be imprisoned by file types and software incompatibility. Because much richer information can be described in XML than with HTML, Internet searches will be far more focused and robust than they are at present.

Linked or embedded style sheets enable the data within XML documents to be displayed on the fly in a variety of different ways, depending on the requirements of the end user. Because XML separates data from presentation, XML documents could contain information that would be visible to some users and invisible to others, depending on context. Instead of making many small requests from the server, XML-enabled browsers would download data in larger chunks and manipulate it offline, relieving network traffic bottlenecks. Users can filter the information themselves, 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.

One application of XML will allow users to access different aspects of a single database and display them in a customized way. For example, in a shared project database, an architect's Web browser might be configured to display only geometric data, i.e., the physical form of a design. The contractor's Web browser might display only information about schedules and costs, using exactly the same set of data stored on the same remote server. The architect and contractor would be able to work with the information displayed using Java applets downloaded when needed by their browsers. The architect would not need to have CAD software on her laptop while accessing the database from her hotel room, because all of the functionality needed to work with the model would be supplied by the applet itself.

With XML and object-oriented CAD, entire sets of construction documents could be prepared in the form of live Web sites rather than a collection of static documents. 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.

The promise of Internet-delivered product data goes far beyond replacing brochures with Web sites. Products could be classified with far richer detail than they are at present. 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. Java applets could allow a Web site visitor to extract data about products in a variety of useful ways: comparing the price and performance of various models, checking available options and finishes, or studying the energy consumption of a product when used in a particular sun exposure.

From there, it isn't hard to imagine product models also carrying information about life-cycle performance. 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 life-cycle not of one building but of all buildings known to contain the product. Performance issues, maintenance, and replacement data could all be integrated into such a "living" specification.

Fulfilling the vast potential offered by networked organizations, XML and object-oriented CAD will take an unprecedented industry wide effort—and a willingness of architects to adopt new roles. Unless they seize this opportunity, architects of the future may be little more than "skin and core" designers—just another specialist among many—and architecture as an independent profession may become obsolete.

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