# Strategies for Integrating Computers in Architectural Practice

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How are architects using computers? What are the real benefits of the technology? What impact does it have on the way architects design? How should designers use computers? These are some of the questions architects are facing today as they implement computers in their design practices.

A common mistake in evaluating the impacts of information technology is that it is usually seen as an isolated phenomenon and assessed in terms of mere technical competence. But computers are part of a larger phenomenon—one that will ultimately change design-build processes, organizational structure, and company culture.

This article will examine the profiles of three companies that are integrating information technology in their design functions (HMC, Frank O. Gehry & Associates, and Boeing Co.). Even though each firm faces particular challenges, all three are very representative of the main issues design organizations are facing today when they integrate information technology in their design function.

## HMC GROUP, ONTARIO, CALIFORNIA: A STORY OF TRADITIONAL CAD IMPLENTATION

The first case we will analyze, HMC Group, follows a path made traditional by most architectural and engineering offices over the past 15 to 20 years. In 1986, HMC was a 90-person architectural company based in Ontario, California. A relatively large design firm, they have been in business for more than forty years. Since the late 1970s they had been observing how an increasing number of their competitors were using computer-aided drafting (CAD) and, in 1985, HMC decided to implement their own system. They followed tradition and took a mainframe-based approach. From 1985 to 1990 their CAD system grew from 3 to 13 VAX terminals running Intergraph software. But the truth was that the system was rarely critical in getting jobs or instrumental to delivering a more efficient or better service. At HMC, the system was just a way of saying to clients and competitors, "We have it too." In fact, as with a majority of firms in those years, most of HMC's architects were still drawing by hand and passing design sketches and drafting documentation to a small number of computer experts and operators.

In those early days of CAD, typically only the large architectural firms such as HMC—firms with more than 80 employees—could afford the technology, but the high prices of mainframes limited even their systems to only a small number of stations. This situation was to change with the advent of Personal Computers (PC); by the late '80s, the increasingly economical PCs and Unix workstation were competitive with CAD mainframe systems. But, large firms such as HMC were still balking at the extra financial and administrative burden a switch would mean.

HMC's president James D. Chase, says that things began to change in 1990, when "a large number of clients began demanding most of the work in CAD." By this time, HMC's five-year-old system was having difficulty keeping up with clients' demands. The VAX mainframe system was expensive and not very flexible. It was also limited in terms of expansion and had high maintenance requirements. But it was the advent of a major medical project, in 1991, that made HMC decide to buy several 386 PCs. The firm also changed software vendors and migrated into AutoCAD—an emerging popular CAD software for the PC environment. "In addition to the CAD software," Chase says, "we adopted some word-processing software and spreadsheet software to establish a prototype PC workstation."

But the choices and challenges were more complex than just a matter of hardware and software. HMC management began discovering that all this automation required major financial and managerial considerations. Other firms, they saw, were feeling pressure to become more efficient and reduce their labor costs to cover the new need for capital investment in computer equipment, software, and training. Managers were beginning to urge CAD technology upon their professionals; the old arrangement of having CAD operators was just not efficient. Firms like HMC that had successfully implemented CAD on PCs started company-wide in-house training in order to develop computer literacy among their professionals. Computer-literate architects were appointed to newly created positions such as "CAD managers" or "CAD directors"—positions that became the change agents or technology champions charged with diffusing the technology.

By 1993, HMC had a company-wide, highly networked PC system linking all their offices. More than 90 of their 155 professionals had been trained in CAD and were delivering 75% of their projects in digital format. Architects that are working in firms like HMC, where computer literacy is high, report that they are much more efficient in producing drafting documentation with their PC CAD systems today. They now can create, store, edit and share almost instantly large amount of data from their desks, which was, of course something impossible using traditional hand-drafting procedures.

By 1995, PC CAD technology became without doubt the most important piece of technology introduced in architectural offices in the last 20 years. CAD stations are quickly replacing drafting tables, and CAD literacy is fast becoming a required skill for entering the profession.

## FRANK O. GERHY & ASSOCIATES: IMPLEMENTING COMPUTERS TO CHANGE DESIGN-BUILD PROCESSES

If PC CAD is the most important piece of technology implemented in architectural practice in the past 20 years, we can say that networking technology will be the most important development of the decade to come. Organizations are beginning to discover that although operations such as drafting became more efficient with PC CAD, the whole design-build process did not. New ways of networking, sharing, and coordinating information through computers will change the ways designers, engineers, and contractors collaborate. The changes will pose new problems as well as provide many new opportunities that will ultimately bring into question centuries-old design-build processes in the architecture, engineering and construction (AEC) industry.

The architectural office of Frank O. Gehry & Associates is a pioneer in this technology and a good model for understanding how the AEC industry will began using information technology in the next decade. A 70-person company based in Santa Monica, California, Gehry's office has done prestigious design work around the globe and is one of the best known architectural firms in the world because of its sculptural designs. These designs are complex, and very difficult to describe and document with traditional two-dimensional architectural drawings. The Santa Monica office began using computers heavily in the early 1990s as a way to solve many of the geometric and construction problems that Gehry's design posed. From the beginning the use of computers at Gehry's office was associated with pushing the limits of what could be built, says James Glymph, principal. "The problem for us, and the whole reason to get into computers, was about the process of building, and not about producing traditional drafting documentation," Glymph says.

One of the factors driving the use of information technology at the firm was the complexity of Frank Gehry's designs. For example, in the Disney Concert Hall in Los Angeles, one of the largest projects Gehry's ofice work in the 1990s, a large amount of the design documentation was done using computers. The Disney Concert Hall is a 200,000-square-foot building which includes, on the exterior, a series of dramatically shaped curvilinear stone walls. It would have been impossible to describe the shape of the stone walls with traditional two-dimensional drafting techniques. Thus, the usual design documentation was never used for this project. Instead, Frank Gehry's large cardboard models were scanned directly by three-dimensional optical and mechanical digitizers. Once the model was in the computer, Gehry's architects were able to develop the shop drawings for each individual stone using a software called Catia—a numerically controlled (NC) software used in the aerospace and car

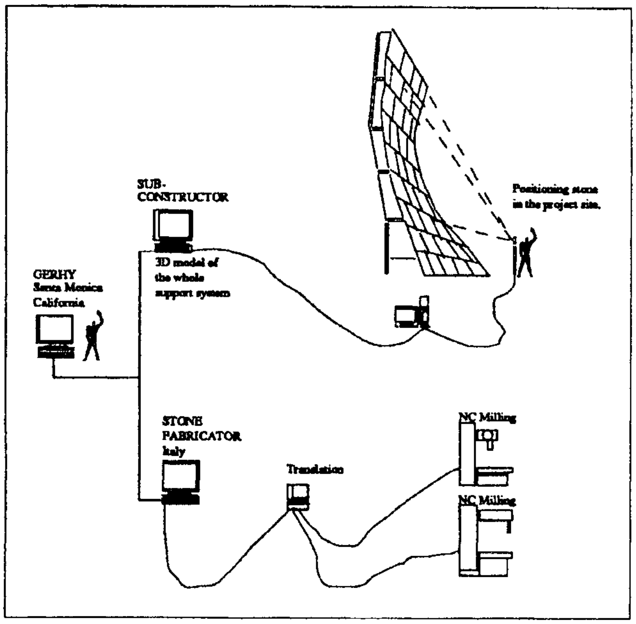


Fig. 1. Proposed digital connections among Ghery's office, sub-contractors, and fabricators.

manufacturing industry. They had learned that the NC software offered them many new possibilities such as sending information to the contractor. They could also send the information to the fabricator running the cutting and milling machines—linking the design directly to fabrication.

Gehry's office presented a mock-up of one of the curved walls of the Disney project in the Venice Biennale in 1991. With the Catia system, the architects were able to produce the shop drawings for all the stones in a week, a feat "impossible by hand," says Glymph. The drawings were sent to an Italian stonecutter, and "The wall was constructed ahead of schedule, with tolerances of 1 millimeter."

After five years of experimentation, Gehry & Associates now routinely use information technology to tie the architect much more closely to the whole process of building and construction. They are beginning to use information technology to tie the architect much more closely to the whole process of building and construction. They are beginning to use automated milling and cutting machines to cut the stone and metal directly from the computer models generated by designers. Glymph thinks that the Lewis Residence in Cleveland, Ohio, is the project that will end up pushing the limits in their use of computers. Glymph says, that they are looking at several ways to integrate CAD/CAM technology in the building process, which will include steel bending, stone milling, glass bending, glass cutting, laser cutting, and all kinds of functional operations that will be involved in the fabrication process.

Moreover, says Glymph, Gehry's office is requiring other participants in the building process to use similar software, so data can be shared. The company is involved now in finding relatively economical and quick ways of creating links between their office and engineers, consultants, and contractors. According to Glymph, the office is enjoying strong support from the client of the Lewis residence and believes that this to be a very good opportunity for integrating the whole process since "the project is a private residence and does not require the whole set of legal responsibilities that larger projects have." Gehry's office is planning to line up with an architect in Ohio who will be put in the site with a computer station. The contractor and surveyor that they will select will also have to be proficient with their computer system. Since they would stay out of traditional documentation as much as possible, all the surveying and layout would be done on the site computer. With this project, Glymph says, "We are trying to take all the pieces we discovered along the way and putting them all together."

Virtual design-build studios linked through computers and scattered around the globe are a recent phenomenon, but one that is spreading very fast in design organizations of many industries. Design-manufacturing processes at companies such as Texas Instrument, Timex, Whirpool and Boeing have already benefited from these developments. These companies have recognized that better productivity is achieved not only by automating existing tasks but by using computers to improve the design process.

## THE BOEING COMPANY: THE IMPACTS OF COMPUTERS IN ORGANIZATIONAL STRUCTURE AND CULTURE

As companies continue to pursue the use of information technology to redesign old processes, they will begin to realize that this cannot be fully achieved without significant changes in the organizational structure and company's culture. The integration of information technology in the design of the 777 aircraft at Boeing Company illustrates these challenges and also presents many of the issues which will occupy the AEC industry in the future.

Boeing built the 777 airplane as part of an effort to stay in the vanguard of the airplane business. Probably the most daunting task they faced along the way was the pre-assembly of the 777 entirely by computer, prior to manufacturing. This meant a completely paperless design-build process. To achieve this objective the entire design had to be computer-drawn in three dimensions using computers and shared through high-speed networks with partners around the globe. It was called the largest CAD/CAM project ever.

> To develop the plane, Boeing linked together 1,400 IBM workstations and clustered four IBM mainframes. A total of 1,700 engineers, toolers, mechanics, and project managers were all linked together to simultaneously work on the project. Boeing's Seattle offices were also linked to its pre-assembly plants in Japan and Kansas—where digital schematics were sent instead of paper to build parts of the plane such as the body section or the cockpit. Boeing also linked in all of its suppliers to enable them to have access to detailed renderings of parts of the 777 (Moeller, 1994).

The idea made sense: people could communicate faster and more accurately through computers, and this, in turn, would allow for early detection of design changes and errors, reducing design-to-manufacturing time and improving the final design. But in practice, things developed somewhat differently. After Boeing installed the computer system, people were reluctant to use it as intended. The first time they used the system, the engineers did not release their parts until the date they were actually due, says Boeing's president Phil Condit. Condit explains, that in response management put up big signs on computer stations exhorting employees to "release early and release often." "It did not work," says Condit. Five design cycles went by before management began seeing collaboration and concurrences in the design-build process.

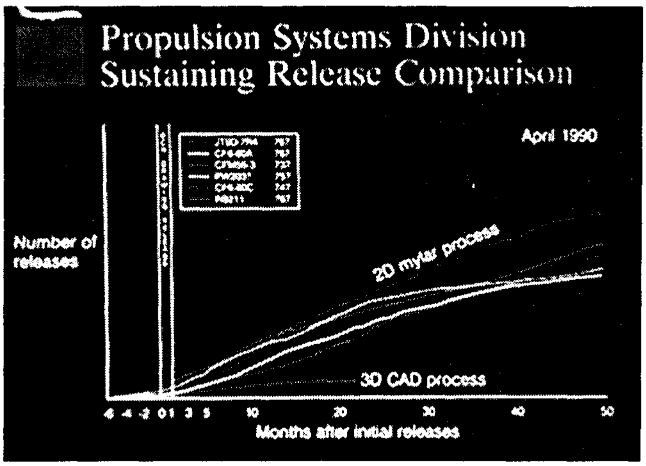


Fig. 2. Comparing number of drawing releases between the 2D mylar process and the 3D CAD process in the design of the 777 at Boeing. Source: http://pawn.berkeley.edu/~shad/b777/index.html.

Boeing began to understand that changing the design-manufacturing process involved more than acquiring a very sophisticated computer network. The task required a whole new way of thinking about their design process, the organizational structure and the culture of the firm. Up to this point, Boeing had a very linear design-to-manufacturing process. Drawings usually went linearly back and forth from design, to planning, tooling, fabrication and manufacturing, and then back to design. On the average, every single drawing got changed 4.5 times in the process. Traditionally, the structural organization of Boeing Co. was organized around functional and product-based units. The company was divided into the divisions trough which the linear design-build process moved. Engineers at Boeing were rewarded individually for their work and would climb the ranks of the company only through their specific functional or product-based departments.

To think that merely providing electronic design capability and a high-speed network system would allow teams to communicate and collaborate more effectively was just unrealistic, says Condit. "Nobody wanted to release their parts often and early in the process, because nobody wanted to be prematurely criticized for their work."

> Changing how people work was also a major undertaking. Olson [director of computer systems for Boeing] said that engineers at Boeing had a hard time learning how to work with a lot of different people on a "team" rather than just concentrating on "their own specific piece of the project...by the time it was complete, everyone on the 777 project came to grips with the concept of the team, and now most of them would not go back to the old ways of doing things...but the changes took a while to take hold"—Olson said (Moeller, 1994).

To make the new system work, engineers at Boeing had to learn how to develop products as a team and to reward team work. Condit says, that they began to do a lot of training, research and observation, he calls its "people issues," that are associated with the integration of computers and new design processes. He explains that they began observing and learning from many other companies such as Toyota and Ford.

Today, the "people issues" Boeing has addressed have not only transformed their design process but have also fundamentally changed their organizational structure and culture. As a result, designers at Boeing now are comfortable in a design-build team environment—an environment in which they can fully take advantage of their new networking system.

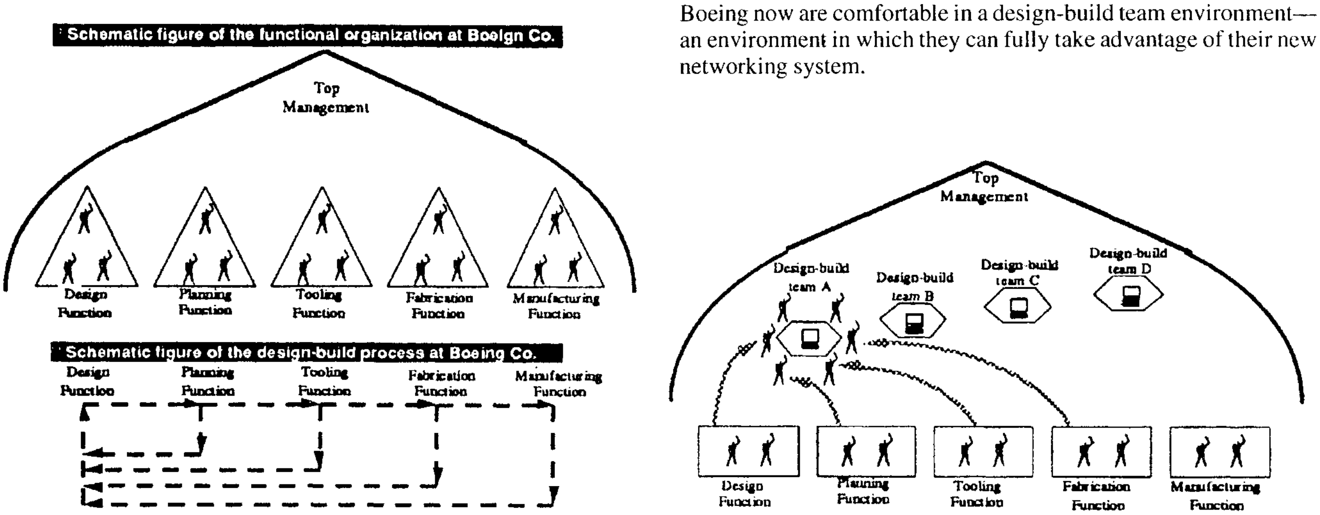


Fig. 3. The illustration on the left side shows the traditional design-build process and organizational structure at Boeing Company. The illustration on the right side shows how the organizational structure at Boeing Co. was redesigned after using the new CAD/CAM system in the design and development of the Boeing 777 aircraft. The old functional structure disappears. Instead, core design-build teams have a much more important role. In this new arrangement traditional divisions are mantained just as a labor pool from which team managers can obtain their members.

Furthermore, Condit says, "the old functional structure and individual reward system are drastically changing at Boeing." He explains that management is beginning to learn how to compensate and reward teams. Boeing is also learning how to move away from its functional organization and organize around a number of core design-build teams of 15 or 16 people with members from different disciplines. Finally, as a result of introducing computers to improve its design-build habits, the company has ended up with much smaller organizational entities and is spending a lot more time talking about processes, investigating how a good design-build team works, and looking much more closely at how people interact at work. During the design stage, Boeing is paying much more attention than before to manufacturing issues and, as a result, the firm's engineers and partners around the world are linking daily with the Everett, Washington, factory. More than just hardware and software, it's the process of learning to use the system as a team that led Boeing into a new era in design-build collaboration.

According to Larry Olson, director of computer systems for Boeing: "by making the move to CAD, we were able to cut the rework and error correction time by more than 50%...while it took almost the same amount of time to develop the first 777 using CAD as it did using pen and paper, the time to build future 777s will be at least 50% faster." By developing the plane on-screen, Olson said that Boeing was able to run full-scale simulations and correct conflicts in the design without ever having to build a mockup "saving us an enormous amount of money. There is no way to compare the savings that we are going to realize using CAD versus older methods that we formerly used." Now Boeing is porting Catia to all of its plane designs. Olson explains that Catia is being used to develop the 737-700 jet and the next generations of the 777 "heavy weight and stretch versions." Boeing is also now in the process of moving all of its 2D schematics for its existing airplane models and converting them to Catia for future changes and modifications (Moeller, 1994).

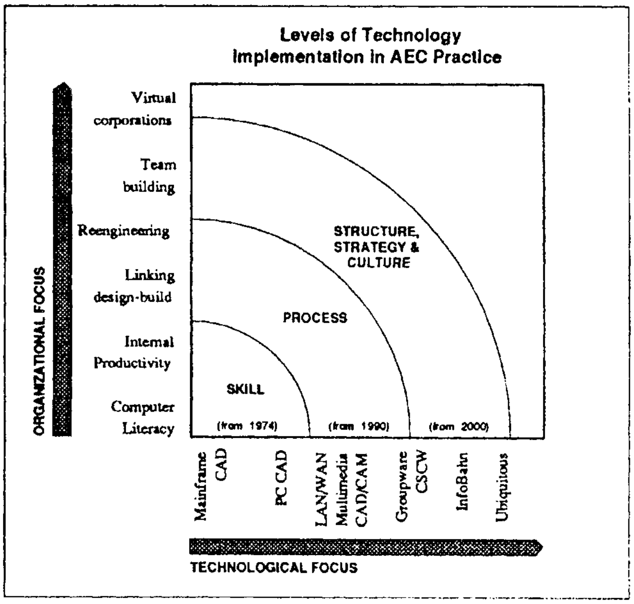


Fig. 4. Designers are adapting to information technology in three basic steps. The first involves changes in skills associated mainly with CAD technology, as the whole company becomes computer-literate. The second wave involves "process" changes associates with networking, groupware, CAD/CAM integration, and the redesign of job processes. And the third and final wave arrives when firms realize that to take advantage of the new technology, they have to implement major organizational and cultural changes. Source: Andia, A., 1994, 1998.

## CONCLUSION

I have visited more than 100 Architecture Engineering and Construction firms and researched several product design and manufacturing companies in the US and Japan that are implementing information technology in their design functions. My observations—as embodied in the above three cases—indicate that we are dealing with an evolutionary process of adaptation to a constantly changing technology. Although this may sound obvious, it is something managers and designers usually forget when they reflect about the integration of computer systems and design. I think that we are experiencing at least three major eras or levels of change through which designers are adapting to computer technology (Andia, 1994 and 1998).

The first wave of change is exemplified by firms such as HMC Group, which automated only low-skilled tasks such as drafting and wordprocessing. I call this period a "skill" change era, because technologies such as CAD have merely replaced manual "skill" procedures. CAD provides a wide variety of benefits—gains in drafting productivity, a more simplified means of storing and sharing data, better simulations, and better presentations—but has not had a major impact on how buildings are made or significantly affected building costs. Today many firms are asking questions that take them beyond "skill" productivity gains and are beginning to look for the real information-technology payoff.

New developments in networking, multimedia and telecommunication technologies will ultimately contribute to a second era of changes in the profession. I call this second period, an era of "process" changes, because these technological innovation are promoting more communication and collaboration between the different participants of the design-building process in a way that will ultimately change it. Firms such as Frank O. Gehry & Associates are realizing that the real benefits of these technologies lie in redesigning job processes.

As companies begin to change their job processes by using information technology, a third wave of change will emerge. As the Boeing case illustrates, the increasing power of technology, in conjunction job-process-redesign efforts, will revolutionize the organizational structure and culture of entire organizations and industries. These changes, along with the new political realities and a globalization of markets, should suggest to us the challenges that will face the AEC industry in the decades to come.

## NOTES

The previous paper was written without major interruptions about methodology to provide a solid narrative about the findings. The language and the examples, found in those cases, were chosen to reconstruct and illustrate how the discourse about technology is been shaped in the AEC industry. The author found it necessary to develop that narrative to provide a recognizable framework to which any AEC practitioner could relate when reading this text. The idea was to immerse the reader in a reconstructed reality so that he or she could develop a better understanding of the phenomenon occurring when computers are implemented in architectural practice. The strategies and validity of reconstructive methodologies is discussed at length by sociologists of technology such as Kling (1991), Dunlop (1991), and applied in similar investigations in management in the work of Liker (1992), and Beatty (1988).

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