PENCILS AND PIXELS

Paradigms in Architectural Design Computation during the Past 30 Years

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INTRODUCTION

How should designers and academicians use computers, and what are the real benefits of computers? Are computers part of a larger phenomenon, one that will change the design-build processes, organizational structures, and design cultures? These are some of the questions architects and architectural professors encounter daily as they integrate computers with practice and education.

Following is researched information about the "computerization" process of architectural practice and education during the past three decades. The concepts developed here are part of a research that included reviewing existing literature, and conducting interviews at more than 140 U.S. and Japanese firms, and universities that are using computer technology in design (Andia 1997).

COMPUTERIZATION OF ARCHITECTURAL PRACTICE

The introduction of mainframe, CAD software, PCs, and networks into architectural practices has had two different impact levels since the first commercial CAD software was introduced in 1974. From 1974 to the early 1990s computerization impacted professional offices almost exclusively at the "skill" level. In the 1990s the discourse in practice evolved from gains in drafting productivity to creating more efficient design-build processes.

Computerization of Drafting Skills (1974 - early 1990s)

Initially, *The Mainframe CAD Period:* with large CAD systems, in-house programmers, independent information technology groups, and software strived to be "total solutions" which were predominant characteristics in the early period of "skill" computerization in architectural practice, which occurred during the 1970s in the United States and the 1980s in Japan. At an average cost of $50,000 to $200,000 per seat, to purchase and maintain CAD's mainframe hardware and software, the number of CAD users was few and it was monetarily feasible for only a few large firms. Thus it was impossible to widely spread the technology within an AEC firm, and therefore CAD was being used for only 5 to 10% of the projects.

Secondly, *The CAD Operator Period:* with large, in-house CAD systems such as "ARK2" from Perry, Dean and Steward, "AES" from SOM, and "HOKdraw-HOKimage" from HOK became obsolete when faster PCs and better off-the-shelf software entered the market in the mid-1980s. CAD operators and PCs replaced the information system department and their mainframes, during the late-1980s in the United States and early-1990s in Japan, with only 10 to 20% of projects drawn using CAD. Shortly, architectural offices realized the redundancy of hand drawing then drawing the same information using CAD.

Thirdly, *The PC CAD Period:* as cheap PCs and easier software exited the isolated IT (Information Technology) rooms to be situated on the architect's desk. During this era, unlike the previous, the transition was easier for small offices as opposed to the large ones that had made grand investments in the previous technologies and were reluctant to change to this new technology. Their reluctance was short-lived since by the end of the 1980s, in the United States, and by the beginning of the 1990s, in Japan, most institutional and corporate clients required that final drawings be in digital format. Firms made the transition by conducting in-house CAD training. Worried senior management became "executive champions" for promoting CAD literacy programs; computer literate professionals became the "CAD champions" or agents that distributed the technology within the firms. Most large and medium U.S. firms, by 1995, had substantially increased their computer literacy levels with approximately 75 to 100% of their projects produced using CAD.

Computerization of Design-Build Work Processes (early-1990s - mid-2000)

Networking technology will be the most important development for the coming decade, similar to the level of technology that PC CAD assumed in architectural practices during the mid-1970s to the mid-1990s. During this time, computers changed the architectural profession by creating a simpler and more efficient means of drafting, but the process of design-build remained constant. It is now that the process of design-build is transforming due to the technological impact of networking which creates an easier means of sharing and coordinating information via computers among multiple architectural trades. The creation of these transformations will provide new opportunities and pose new questions for the AEC industry. In the 1990s there emerged two major impacts within networked technology as it affects the everyday "work process":

First, *the period of "Data Networks,"* (1993-98 in the U.S.) LAN, WAN, and the Internet are examples of some of the "data networks" that were acquired by companies, specifically for document management, system maintenance, improved software management, printer sharing, and plotter sharing. During this period, it was assumed that quantity, transmission speed, and availability were directly related to increased productivity within an organization. AEC offices later discovered that the benefits of computerization were how professionals organize, perform, and manage the design-build processes.

The *second period of "Concurrent Design"* emerged throughout the 1990s in many other industries in the United States. Terms like "concurrent engineering," "design for manufacturing," and "reengineering" addressed this issue of the actual changes in people's work processes within the 1990s corporate America, and later emerged in the AEC industry. Through evaluation and analysis companies would be able to redesign procedures, not just automate the existing tasks, which would significantly improve business and customer satisfaction. The idea of redesigning procedures spread quickly among AEC professionals but complete implementation became impossible due to the necessity to holistically understand the business procedures they wish to redesign. A holistic understanding of all the trades and their processes seemed impossible since, unlike many other industries, the AEC industry is very fragmented and seasonal. The product, a building, is individually designed, managed, and executed with added variables like local trades, business environment, legal issues, and traditions. AEC firms were transformed through the implementation of information technology gradually into the daily practice with improvements discovered from one project to the next, thus a time consuming process.

One of the best and most important examples of this emerging period of architectural computerization was at the office of Frank O. Gehry & Associates. During the 1990s Gehry began using computers to solve construction and geometric problems posed by his designs. In the beginning, computers were used to push the limits of what was buildable, not about the production of traditional construction documents, but as the commissions began to grow the complexity of the designs increased. The implementation of the this technology began with the fish sculpture for the 1992 Olympic Village in Barcelona, and then the 200,000 square-foot Disney Concert Hall (Novitski, 1992).

After a decade of computerization, Gehry & Associates, currently use it to unite the architect with the construction and building processes. For example, they used computer models generated by the designers to send to automate milling machines to fabricate or cut the individual pieces. Digital models are utilized, in conjunction with lasers, for site positioning thus better describing the construction process. Due to these modifications, alterations occurred with the legal and organizational relationship with the inclusion of contractors prior to the completion of the construction drawings; thus eliminating the bidding process based upon finished construction documents.

Another technological networking advancement, that occurred during the "Concurrent Design" period, is the introduction of virtual design studios, which are able to be located anywhere around the world, but linked via computers. This development has already benefited companies such as Texas Instrument, Timex, and Whirlpool. AEC firms are being networked by new B2B companies (i.e.: Cephren, Buzzsaw, and Bidcom) to ease communication transmission difficulties and AEC's "work process."

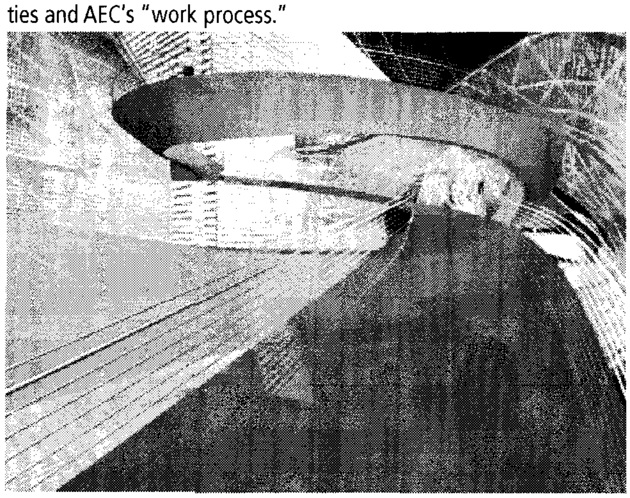

Fig 1. Work from student Rick Dunn, Design 7, 2001, FIU, Miami. The image flowing through media replaces the rational plan-section construction of form. There is no longer frozen form but retinal sensations of space. Mobile and unstable media has a tremendous retinal spatial richness. The form-design process becomes more experiential than rational.

ARCHITECTURAL EDUCATION IMPACTED BY COMPUTERS
Design Methods (1960s - 1990s)

Born inside academia and the computer science community, the first attempts to create a relationship between computers and architecture occurred during the 1950s. The direct descendants of these studios were the "problem-solving" or "systematic methods" which were popular in the 1960s computer science community.

During the 1960s, computers were viewed as machines that could eventually achieve human intelligence, "giant brains." With this goal, designer's rationale was reduced to theories and models later to be automated. "Computability of architectural design" research was popular in the 1960s and 1970s architectural academic community. The field of "Design Methods" emerged in academia from the intense criticism of scale drawing, the creation of a new systematic approach to design, and the progress of the area of computers. The most popular of the design methods were: Christopher Alexander's "misfit variables," Nicolas Negroponte's "architectural machine," M. Asimow's design elements, Christopher Jones' "factors," Bruce Archer's "sub-problems," Nigel Cross "automated architect," and Horst Rittel "issue based information systems." These theories generated the basis for much of academia's early architectural software.

The "Design Method" projects, theories, and devout believers began to be reduced to a small number of architectural and design courses, in the U.S. and Europe, during the late 1970s. The information that remained was the foundation for the initial commercial CAD systems.

CAD Visualization: Imitation of Practice (late-1970s - today)

Professors and researchers in academia were developing software, in the mid-1970s to the mid-1980s, for architects. Some of the software was based upon the "Design Methods," while others were developed as in-house CAD systems, and others were a combination of the two, but regardless of its basis, it remained isolated from the traditional design studios and other architectural courses. One reason for this was computer accessibility; the ratio of students to computers averaged 1:50. The CAD software developed during this time that became successful was based on graphics, not on systematic "Design Methods." By the late-1980s, with the combination of cheaper PCs and available CAD packages, the development of software by academicians decreased; they were forced to learn the emerging CAD software and its standards.

During the mid- to late-1980s, the first computer labs began to appear with the student to computer ratio increase averaging between 1:30 to 1:20. Schools created courses for the distribution of CAD literacy, but throughout this time the majority of architectural professors resisted CAD from entering the studio environment. One of the reasons for this resistance was the idea that the suggestive nature of hand drawing and modeling would be lost with computer drawings. Adding to the alienation of computers in architectural education, the professors who were hired to teach computer literacy were often recent graduates rarely holding a tenure-tracked position.

By the early 1990s, CAD courses became part of the architectural education core, at most schools. The acceptance occurred due to "practical realism;" the majority of medium and large architectural firms had a high computer literacy level, and CAD skills became a requirement for recent graduates to receive employment. "Practical Realism" directed the schools' selection of hardware and software; most used PCs with AutoCAD, Microstation, and 3D Studio. The majority of architectural schools employed approximately one tenure-tracked computer professor per 200 students, and increased the quantity of computers to 10 to 20 stations per student. At this time the introduction of digital tools into the studio work became acceptable.

The results of the introduction of digital tools into architectural studios had little effect on design projects. Projects continued to be presented by the use of the traditional means of plan, section, and elevation, with CAD used solely for final presentation. Design rationalization continued to be executed by hand (drawn or modeled).

Paperless Studios (early 1990s - today)

A few academic institutions, in the 1990s, chose not to follow the professional practice and the majority of schools by using PCs with AutoCAD, Microstation, and 3D Studio. For example, the School of Architecture at Columbia University began using high-end movie industry animation rendering software (Alias/Wavefront, Softimage, and Maya) to replace the traditional hand drawn design process, thus the "paperless studio." Character animations, fluid diagrams, and other special effects enabled by the use of the software proved to be a quick and valuable tool for rendering diagrammatic ideas like circulation studies and building program variations. "The software soon proved to be more useful than a mere rendering tool; it started to inform, and transform, the design process." (Cramer and Guiney, 2000)

Professionals using this new method of "paperless" design include the offices of "Paperless" offices such as Greg Lynn, NOX, Oosterhuis, Reiser + Umemoto, O.C.E.A.N., and UN Studio saw their reputations spread quickly through the world of architecture. The retinal effects of 3D computers not only transformed the market for new shape searchers but also altered the design-form making process. Design desitions can be tested immediately (Lynn, 1998). Also questions of materiality can be suspended: "The current generation of (digital) architects is already free. We have already forgotten history, shaken the metaphors belonging to wood, bricks, and steel. We have already seen emptiness. Now it is time to redefine materiality. Let's rethink materials in relation to organizational structures." (Van Berkel and Bos, 1999)

Resistance to the "paperless" design culture encountered two different criticisms. The first type of criticism addressed these designs as architectural extremists that solely design non-buildable "utopias." Columbia University addressed this criticism by appointing Frank Gehry to the position of distinguished professor. The emerging "paperless" firms began shifting the race, from "new design effect" to exploring new materials and fabrication techniques such as CAD/CAM fabrication. The decade of the zeros will be used to prove the point. The second type of criticism is more profound. It accuses the "paperless" architects for being too conservative. The critics point out that instead of revolutionizing the profession, the "paperless" designers are just using computers to continue in the endless new aesthetic searches. The same hunt that characterized 20th century avant-garde architecture.

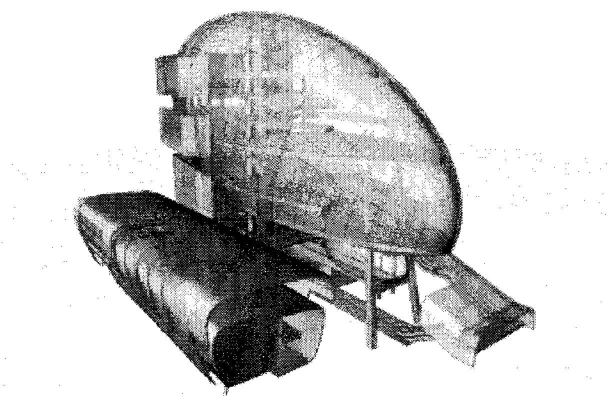

Fig. 2. Paperless studio work from student Shigeru Otsuki, Undergraduate Design 7, 2001, FIU, Miami.

Information Architecture (mid 1990s - today).

The second level of criticism to the paperless studio experience has entered academia and some architectural practices causing an emergence of interest in the impacts of digital technology on society today. Their discovery is that space can be created physically, psychologically, and communicatively, and that architecture need not be concerned with solely the construction of a single building, but instead enter the realm of a mixed urban reality. "Click and bricks" urbanity is an example of architecture being both "cyber/virtual" and "real/physical" concurrently. The studies have involved the observance of specific human activities like banking, working, studying, shopping, and etc., which are being transformed into more distributed hybrid "cyber/real" spaces, no longer the purely functional physical building. Architects are equipped to investigate this new method of design since for over two thousand years they have been trained to develop clear spatial designs, programmatic organizations, sequencing of human interactions, sense of destinations, and memory experiences. For example, these architects study what is lacking in virtual environments like the Internet, they have discovered that the user is often lost, loses a their sense of time, lacks memory of where they visited, and surfs randomly.

Different than traditional architecture, "click and brick" architects have the ability to affect the environment over a longer period of time by the changing of the images, memory, and usability of real buildings with the use of networked software and, or, an environment that can be manipulated by the user.

"Information Architecture" or "Cyber Real Architecture" emerged initially during the early-1990s in theoretical writings, and then subsequently advanced in the late-1990s into professional practice (Mitchell, 1995; Castells, 1989). Examples of such professional works are Asymptote's NYSE Virtual Stock Exchange and Guggenheim Virtual Museum, Rem Koolhaas new AMO office, ETHWorld cyber/real university campus, ModernCool and 2069 Inc. drive-thru shopping centers, and Lennon and Associates emergency rooms.

The subject initially became popular in academia as a semester long course, but with the increased number of followers new departments and degrees are appearing in schools (i.e.: "CAAD postgraduate programs and several learning environment" at the Swiss Federal Institute of Technology Zurich (ETHZ); "infARC" program at Bauhaus-Weimar; "New Cybernetic Design" program at Universidad Internacional de Cataluyna, Spain; and "Informatics Architecture" program at Rensselaer Polytechnic Institute).

An increasing number of Ph.D. students, at ETH, have the research supporting the computerized teaching environment; an example of this is "Alterego." "Alterego" is a website inside which the students explore spatial exercises, for example: they use three-dimensional digital cubes to create different types of spaces, which are easily manipulated with the use of the 3D VRML software (Engeli, 2001). Traditionally this exercise would have been executed using cubes of balsa wood. Some of the benefits of using the digital cubes, as opposed to the physical cubes, are that the surfaces are easily animated and textured which creates a moving environment. As part of continued teaching research, the learning space is completely designed at ETH.

The research conducted at ETH and Weimar, for approximately the past five years, has created questions regarding this emerging paradigm: Are architects capable of being good designers in both the digital and the physical worlds, and, will they be able to be technologically proficient in both worlds? With the advancement of broadband Internet technology and the increasing popularity of Web 3D, these schools are destined to attract increased attention in the future.

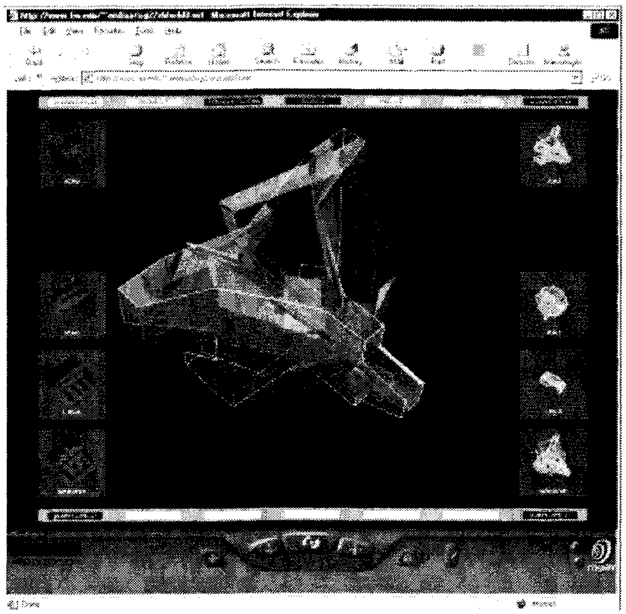

Fig. 3. Piet3D Vrml exercises at Graphics Communication 2, first year undergraduate, 2001, FIU, Miami. Vrml environment RoomZ developed by Kai Stehlke at ETH Zurich stimulates quick networked navigation in 3D.

Virtual Studios (early 1990s - today)

The Virtual Studios or Internet Studios are utilizing technologies that allow remote, both asynchronous and synchronous, design collaborations. Students learn new modes of collaboration and media integration in design practices with the use of technologies such as videoconferencing (PictureTels, VocalTec, Cuseeme, Real Audio), Internet publishing, e-mail, Web3D, and digital modeling. Another benefit of the virtual studios is that the work is able to be exposed to diverse design cultures and is subject to larger more diverse critiques.

During the early 1990s, the first Virtual Design Studios (VDS) were created at the University of British Columbia in collaboration with Harvard, MIT, Washington University, Cornell University, and Hong Kong University (Wojtowicz, 1994). With the use of asynchronous communication technologies, such as e-mail, bulletin boards, FTP, and Internet publishing. Students generally would publish and share information via the Internet and would for final presentations use live ISDN and IP videoconferencing. One of the greatest problems initially was the technical difficulty of obtaining synchronous communication, therefore it was necessary to share design work via servers and the incipient Internet. Generally these VDS would only last two to three weeks due to the extreme demand of time from both the professors and students to create these very structured experiences.

Collaboration technologies evolved and became more accessible, during the late 1990s; VDS began to increase throughout the world

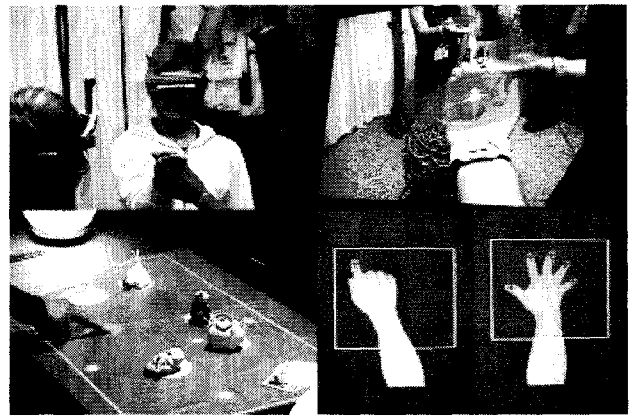

Fig. 4. Images of two mixed-reality environments. In the top images the Head Mounted Display allows user to interact in a game while looking at their team members. In the two images at the bottom computer vision is used to track the movement of the hands of the user.

and were able to endure a complete semester. The advantages of this type of studio range from increased student motivation due to the global nature and cross-cultural experiences, to the accessibility to the designs create a more "democratic" and "populist" dimension of architecture. Also some of the experiences were able to create an interdisciplinary collaboration among students from architecture, engineering, and building construction at U.C. Berkeley and Stanford (Kalay, 1995).

In the United States, during the past five years, there has been a surge in distant education for many other disciplines, but architectural schools have been hesitant to accept this mode of teaching. The Internet Studios remain isolated within traditional architecture, thus making it difficult to conduct an evaluation of the experience.

The result of the studies of "Virtual Studios" shows an extraordinary ability to quickly expose different design cultures, increased transmission of ideas, and increased architectural progress among the participating schools. The negative aspects of this type of studio is the technological demand placed on students forcing them to learn new software which consumes 20% to 30% of their time, and the need to develop more efficient collaboration tools.

CONCLUSION

This research has found professional practice and architectural education developing different discourses of computerization. Professional architects more than truly "revolutionizing" the profession are "modernizing" it, by integrating digital technologies to effectively improve all what conventional architecture has previously represented. While in academia many support this "modernizing" view, an increasing number of universities are becoming test beds for new visions of design imagination, materials, and the realm of the discipline.

Professional architects are combining information technology into their practice via two different means: first, the computer as simply a better tool for doing existing manual work, and second, the computer as a vehicle for changing the relationships among partners in the design process, which in turn may drive new design-build documentation and bidding process, organizational culture and structure. The modes of computerization of architectural practices today are very similar to the discourse developed in other industries, however, the level of change is not as dramatic since the industry is more fragmented, project specific, and organized around very fragile contractual arrangements.

In architectural education there are five interrelated, but divergent, discourses of computerization. The first one, "Design Methods Software," focuses on the creation of intelligent software that can aid, enables, and/or even replaces certain elements of intelligence in the design process. This tradition has a history that dates back to the early 1960's, to early the beginning of computational history.

The second approach, "CAD Visualization," focuses on the development of an architectural education that explores the use of CAD software as "visualization tools" of traditional modes of teaching and practicing architectural design. This tradition is well entrenched in architectural schools and is connected to the long-established vision that professional architecture has had of computers in the past 15 years.

A third attitude, called "paperless or blob architecture," concentrates on the use of existing high-end computer graphics to transform design techniques, architectural imagination, and influence the built environment with a completely new design vision. This is an emerging popular paradigm in design studios across the United States. This approach is almost entirely an academic phenomenon as most of its adepts have very close ties to schools of architecture. In a way this field grows from the avant-garde tradition in architectural history, which has always resisted a conventional architecture and has searched for new formal expressions.

In a fourth posture, "cyber/real architecture or information architecture," is seen as an arena to explore the new virtual and physical dimension of urban habitation. It attempts to remove design studio preoccupation from only the physical world of buildings, and attempts to reposition it to look at its relation to virtual architectures. This area emerges from a resistance to the apparently exclusive aesthetic objectives of "paperless" architects and the extraordinary enthusiasm brought by promising new 3D networked spaces. It is born academically with the tools and the cybernetic tradition that promotes a more hybrid nature of urban functions and spaces.

Finally, a fifth academic experience, "Virtual Studios," explores a parallel dimension of architectural communication in the digital era. These events have the potential to become agents of extraordinary cultural change in the traditionally protected academic environments in architecture. As in physics or mathematics, these new academic networks can propel much quicker progress and exhaust more quickly any of the computerization experiences described above.

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