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Architect-Computer Symbiosis

Paul Emmons[1] and Dalal Kassem[2]
[1] Virginia Tech, [2] Kuwait University

Abstract

This paper elaborates on the particular symbiotic relationship that exists between the architect and the computer when working with architectural design programs, by studying the first graphic interface in 1963: Sketchpad. Sketchpad and the computer programs that evolved from it are used in architecture as tools, and are presumed to have powers in themselves beyond the skill of the artisan. However, unlike what happens with traditional architectural drawing tools that are largely transparent to the drafter, in computer aided design drawing the computer is always an active participant in the design process wherein the system by which the commands are executed is mostly invisible to the operator. The new expectation of computer drawing that originated with the birth of interactive computers fundamentally changed drawings' role in favor of maximizing communication with the computer, and the objective of using line drawing for input data was to strengthen the symbiotic partnership between the human user and the computer. The ease of interaction between person and computer in this way was called an interface because it was equal to face-to-face meetings between people. The Sketchpad window implied such a powerful relationship that it was described and imaged to be another being. To demonstrate his new tool, the inventor of Sketchpad chose to illustrate a winking girl called "Nefertiti" that, through a series of changing left eye components, actually appeared to wink from the computer screen at the operator. This figure created by the operator became the identity of the computer, as Pygmalion's statue became human under the creator's touch. This gendering of technology, whether in the movie Metropolis or in Sketchpad, simultaneously allows

its otherness to be comprehended and its threat to be more easily exorcised. Pygmalion's statue and her numerous reincarnations vivify the otherwise lifeless. Maria, the seductive machine in the movie Metropolis, lures one into forgetting one's responsibilities and deprives operators of their self-awareness. And the computer through its drawing function expresses its "ensoulment" as a thinking entity with a human-like face that is sufficient in order for it to "come alive" in the operator's eye.

The ancient story of Pygmalion describes a sculptor who fell in love with a statue he carved and loved so intensely that, as he caressed it, it came alive under his touch (Figures 1+2). In Ovid's *Metamorphosis*, the story of Pygmalion begins with describing a group of women who denied the divinity of Venus and as a result of her wrath, were degraded as the first public prostitutes, "hardened" and "transformed into stony flints."[1] Fleshy humans becoming black stones are followed by white "snowy ivory" becoming flesh. Pygmalion is a tale so fundamental that it endlessly continues to inspire new versions throughout time. Fritz Lang's 1927 movie *Metropolis* hinges on Maria, a chaste and mothering character who is replaced by a robot taking on her outward appearance but is quite opposed in character as sexually alluring and destructive[2] (Figures 3+4). As in Ovid, the robot's hard metallic body transubstantiates into her soft sexuality. The cyborg's first public appearance has her dancing in a cabaret brothel where her creator judges her successful, inasmuch as she arouses men with her eroticism. When perceived as demonic and chaotic, machines have often been portrayed as female.[3] Interpreters have noted the frequent extension of the Pygmalion story into Pandora, where the living statue realizes unanticipated destructive potential.[4]

The longevity of the Pygmalion story suggests its aptness in describing a certain relationship between the maker and the made. We will examine how this special relationship extends between makers and their tools. Tools have long been presumed to have powers (sometimes magical) in themselves beyond the skill of the artisan.[5] Here, we will elaborate in particular on the case of the symbiotic relationship that exists between the architect and the computer when working with architectural design programs, by studying the first graphic interface in 1963: *Sketchpad*.

From Tools to Systems

Architectural drawing has always benefited from the use of tools. A c.2200 BCE basalt statue of the steward-king Gudea holds a temple plan in his lap, along with a rule and stylus.[6] Compass, straight edge, plumb line and square were adapted for architectural drawing from construction sites at which they had been used since ancient times.[7] These tools are, as Aristotle described them, an extension of the hand or *orga-*

non.[8] Vitruvius explains that *organa* are instruments moved "at the skilled touch of a single operator."[9] For architectural drawing, tools contain the architect's geometry. The mason's set square was adapted for drawing perpendicular lines by the high Middle Ages, and yet in 1660 Sir Roger Pratt judged a square to be for the lazy architect who didn't want to use a compass and straight edge to bisect a line.[10] Heidegger suggests that work gathers many pieces of equipment into one whole, and this has certainly been true of the architect's drawing board as it developed with T-square, triangle, and related equipment. Tools are ready-to-hand, having an "in order to" quality that provides particular "affordances" for realizing thoughts without requiring direct attention to the tools themselves.[11] The drawing board construction system allows ready geometrical manipulation in creating architectural drawings.

Unlike what happens with traditional architectural drawing tools that are largely transparent to the drafter, in computer aided design drawing the computer is always an active participant in the design process wherein the system by which commands are executed is mostly invisible to the operator. Hand drawing, through multi-sensorial bodily engagement, invites designers to imaginatively inhabit their drawings. As electronic gaming has shown, computers can also absorb one's body schema within their imagery, despite or perhaps because of the invisibility of its processes. With architectural computer aided design tools, drawing is expected to fulfill a new requirement beyond representation, and that is to perform as the common language between the human user and the computer. This new expectation of drawing that originated with the birth of interactive computers thus fundamentally changes drawings' role in favor of maximizing communication with the computer. Unlike traditional drawing tools which are described in the early computer literature as "mechanically extended man" materializing design conceptions, computers require human beings to become "users" as part of a much larger apparatus, to be "swallowed by the system."[12] Mid-twentieth-century computer theorists, on the other hand, recognizing this condition, called it a form of communication.[13]

From Numerics to Graphics

Early computers relied upon receiving data mainly from stacks of punch cards that provided answers to already determined questions. The punch card system developed from the origin of the word computer, as people who computed results of mathematical equations. Printed mathematical tables were calculated individually by these "human computers." This same attitude continued with early mechanical computers such as Charles Babbage's nineteenth-century computing engines that were informed by the first computer program created by Ada Lovelace.[14] With such devices using only numerically controlled systems with punch cards, there was no possibility of line drawing for input in these early computers. As early as 1960 the experimental psychologist and computer scientist J.C.R. Licklider described this slow form of communication with the computer through punch cards as the equivalent of corresponding with another person by writing and mailing letters that imposed a substantial distance between input and output, computer and user.[15] The effectiveness of the computer's input and output equipment limited to punch cards in the communication system with humans was comparable to the electric typewriter. Licklider recognized very early in the history of the development of computers that the focus should be on the development of computer displays to enhance the user-machine communication system, and he believed that "the pencil and doodle pad or the chalk and blackboard" was the most effective approach to communication between the two entities.[16] As a result, Licklider judged these early input systems as not being able to fully utilize the capabilities of the computer.

In 1963, the first graphical interface with a computer was created at the MIT Lincoln Lab by Ivan Sutherland as part of his doctoral dissertation. Called Sketchpad, this new computer interface was established to allow humans for the first time in history to interact directly with a computer by using line drawings as the input data. This transformed the nature of communication with the computer from "correspondence" to "conversation", with line drawing as the intelligent language that both the human user and the computer would share in dialogue. According to Licklider, the ease of interaction between person and computer in this way allowed for the same creative, generative conditions as might a conversation between people. It was called an "interface" because it was equal to, or even superior to, face-to-face meetings between people.[17]

From Extension to Partnership

Tools are an extension of one's body, but the computer becomes a partner in thinking. With the development of computer aided architectural design systems the computer emerged as a new partner that became an active participant in the design and drawing process. Since making drawings is so central to the architect's creative work of design, the nature of this partnership between computer and designer deserves careful consideration.

A question discussed by many philosophers is: "*How would you determine if a computer produced something intelligent?*" Marvin Minsky, a pioneer in the field of artificial intelligence, answered that the machine is being intelligent if the task it is performing would require intelligence if performed by humans.[18] Another pioneer in the field of computer graphical methods, Steven Coons, explained that the first computers that were used in the past to solve problems required a full understanding of the problem, and to know at the very outset the exact steps necessary to solve the problem. Therefore, in a sense the computer was little more than an elaborate calculating machine. Coons believed that the future of the computer through the development of a graphical interface would change the understanding of the computer from a calculating machine, doing so by opening people's minds to viewing the computer as an almost human assistant with some degree of intelligence.[19]

Licklider compared this new human-computer relationship with symbiotic relationships that form in nature between two difference species where both creatures depend upon each other for their survival. In his paper Man-Computer Symbiosis, Licklider stated:

> The fig tree is pollinated only be the insect Blastophaga grossorum. The larva of the insect lives in the ovary of the fig tree, and there it gets its food. The tree and the insect are thus heavily interdependent: the tree cannot reproduce without the insect; the insect cannot eat without the tree; together, they constitute not only a viable but a productive and thriving partnership. This cooperative "living together in intimate association, or even close union, of two dissimilar organisms" is called symbiosis.[20]

For the computer and its operator, Licklider seems to be claiming an extreme condition of obligate symbiosis where two organisms cannot exist without the other. A facultative symbiosis or biological mutualism seems a less restrictive analogy, for in such a relationship two organisms can benefit from co-existence but do not have to live with the other.[21] Nonetheless, following Licklider's concept, Sutherland also asserted that the human user and the computer could become symbiotic under the proper conditions. In his dissertation, Sutherland writes: "The Sketchpad system makes it possible for a man and a computer to converse rapidly through the medium of line drawings. Heretofore, most interaction between men and computers has been slowed down by the need to reduce all communication to written statements that can be typed; in the past, we have been writing letters to rather than conferring with our computers … The Sketchpad system, by eliminating typed statements except for legends in favor of line drawings, opens up a new area of man-machine communication."[22] As in Licklider's example of the larva and the tree, he explains that each provides something very different in the symbiotic relationship between human and computer: "In the anticipated symbiotic partnership, men will set the goals, formulate the hypothesis, determine the criteria, and perform the evaluations. Computing machines will do the routinizable work that must be done to prepare the way for insights and decisions in technical and scientific thinking."[23]

This model of a symbiotic relationship already suggests some presence in the computer beyond a mere tool. Claude Shannon, known as the father of information technology, also recognized the presence of another entity that exists in the computer and becomes part of design decision-making.[24] This attitude toward the computer as some sort of a collaborator in design has been described in different ways by various architects. Christopher Alexander in 1964 negatively reacted to the computer's lack of design nuance as merely "a huge army of clerks, equipped with rule books, pencil and paper, all stupid and entirely without initiative, but able to follow exactly millions of precisely defined operations."[25] More recently, architecture professor Ingeborg Rocker has posed the uncanny nature of working in design partnership with a computer: "Nietzsche had argued, sitting half-blind in front of his typewriter, that his new writing tool was 'working on his thoughts.' Today, sitting in front of a computer, one may have similar suspicions—how is this new tool working on one's thoughts, and thus on one's architecture? Computation and computer technologies of representation have impacted the modes of conceptualizing architecture as much as they have impacted the modes of production."[26] In the nineteenth century, there was widespread interest in the possibility of conversing with the spirit world through the new technologies that communicated across distances and time such as telegraph, telephone, photography, phonographs and even typewriters.[27] Unlike traditional tools, at some level the computer becomes a partner in design.

Some practicing architects and architectural theoreticians have recognized the presence of another entity when using computer tools in architectural design, and yet the source of this uncanny feeling is not made precisely clear. In comparison between the architect who uses the computer program with the software developer who designed the program, the latter understands the inner workings of the computer whereas the architect as a user often does not. The fundamental approaches and decisions made with Sketchpad have consequently been passed along to a great extent in current interactive computer graphics programs that evolved from Sketchpad.

Sketchpad is described by Nicholas Negroponte, architect and founder of MIT's Media Lab, as an invention of great achievement, for it introduced the concept of dynamic graphics. Understanding this new concept took a decade for people to begin to comprehend the possibilities of computer graphics that got changed with interaction.[28] The Sketchpad window altered the dynamics of working with the computer. Rather than the human user knowing at the very outset the exact steps that the computer had to follow to reach an answer to a pre-determined question, through the Sketchpad window the human user was able to consider possible alternatives with the help of the computer by working directly with the machine at the computer console (Figure 5). This partnership allows for and encourages "emergent phenomena" when unforeseen results come from the computer. Licklider developed this idea in 1968 when he wrote that "to communicate is more than to send and to receive" because communicators do something nontrivial with the information they send and receive. Rather than just a back and forth exchange of information, true communication is "jointly constructive" and "mutually reinforcing" so that when minds interact, new ideas emerge.[29] This is the symbiotic partnership with the computer that was envisioned already in the 1960s.

The Sketchpad window not only presented a new way to interact with a computer, it implied such a powerful relationship that it was described and imagined to be another being. Perhaps this is true in part because the early computer screen was derived from television, so there was an expectation to see life enacted within its frame. To demonstrate his new tool, Sutherland chose in his dissertation to illustrate a "winking girl" that, through a series of changing left eye components, actually appeared to wink from the computer screen at the operator (Figure 6). As anthropologist Clifford Geertz explains, a wink is not a mere twitch, although they may look identical; a wink is not merely physical—it expresses "a conspiratorial message" to another person.[30] Winks impart private messages from the winker to the recipient. Sutherland's winking girl thus proclaims the symbiotic partnership between computer and operator. The cyclopean screen as the eye of the computer invites us to see ourselves reflected on its surface as in another person's pupil, puppet-like. The name Sutherland gave to this cartoon face is "Nefertiti," the Egyptian queen who is still highly regarded as an iconic beauty – her name meaning "the beautiful one has come" – and partly due to the famous bust of her found in 1912 and now in the Berlin Neues Museum.[31] Nefertiti, one of the most powerful women to have ever ruled, lived in the 14th century BCE and established a cult to the sun god.[32] She, the cartoon, existed on the other side of the Sketchpad window and shared a private relationship with Sutherland that was expressed in the gesture of her wink. This figure created by the operator became the identity of the computer, as Pygmalion's statue became human under the creator's touch.

This gendering of technology, whether in the movie *Metropolis* or in Sketchpad, simultaneously allows its otherness to be comprehended and its threat to be more easily exorcised. Like the recurring wink of cyborg Maria in *Metropolis*, who entices men to follow her to destruction as a manipulative Pandora, Sutherland's winking Nefertiti is the image of the computer with whom he collaborates. In the movie, the distrust of machinable industrialism is displaced onto feminine sexuality, and both can seduce the weak.[33] Pygmalion's statue and her numerous reincarnations vivify the otherwise lifeless. Maria, the seductive machine, lures one into forgetting one's

responsibilities and deprives operators of their self-awareness. Unlike Pygmalion's sculpture and the robotic Maria, the computer does not appear outwardly anthropomorphic, but through its drawing function it expresses its "ensoulment" as a thinking entity with a human-like face that is sufficient in order for it to "come alive" in the operator's eyes. While Sutherland never provided a reason for his drawing her, it does allow him to envision his computer partner as female, an other with whom he creates a unity.[34]

Ghost in the Machine

Licklider's proposal for a productive dialogue between operators and computers through an intelligent language is developed by Sutherland as drawing. The screen becomes the input-output device that provides a "medium" for this drawn conversation. Licklider described electrical graphical hardware, which he referred to as "Desk-Surface Display and Control" that are used to aid us in tedious tasks by having a colleague with a different set of skills. In his vision of user-computer symbiosis, the designer "could sketch out the format of a table roughly and let the computer shape it up with precision. He could correct the computer's data, instruct the machine via flow diagrams, and in general interact with it very much as he would with another engineer, except that the other engineer would be a precise draftsman, a lightning calculator, a mnemonic wizard, and many other valuable partners all in one."[35] In this statement, Licklider describes the computer as "another engineer" who has the abilities of a "wizard" that are valuable for an engineer who is using the computer. Clearly, Licklider envisions the beneficiary of this symbiotic partnership with the computer to be an engineer.

Sutherland relates his approach to engineering drawing. In an interview, he revealed a past source for his ideas about sketching: "I had been interested in drawings, mechanical drawings in particular, since a very young age. My father was a civil engineer, and I used to look at his blueprints and try to understand what they meant, and what was important in them and what wasn't. So I was able to read mechanical drawings before I ever entered high school. When the opportunity came to use a suitable computer, it seemed the most natural thing to make drawings with it."[36] The engineer is able to benefit from a symbiotic partnership with the computer because the computer is equipped with the skill of following a set of rules to reach an optimum design solution for a predetermined set of constraints, whereas the architect tends to benefit from a different kind of partnership that does not involve following pre-established rules, but rather expands one's thinking. Already in 1928, Le Corbusier, while lauding the skill of engineers, distinguishes them from architects, writing that the engineer is "inspired by the law of Economy and guided by calculations" while the architect "gives us the measure of an order that we sense to be in accord with that of the world," adding that "he determines the diverse movements of our minds and our hearts; it is then that we experience beauty."[37] The computer interface that is used by architects was conceived for engineering, a different discipline.

When computers were introduced into architectural drawing practices later in the twentieth century, the focus was upon imitating the appearance of hand drawings, rather than a careful consideration of the process of constructing drawings and its role in the architect's imagination. One of the challenges in developing Sketchpad was creating a computer drawing system that utilized the capabilities of the computer while providing a familiar drawing platform for the drafter who was accustomed to traditional drawing methods. As a result, the process of drawing in Sketchpad was designed to imitate the appearance of freehand sketching rather than being a careful consideration of the process of constructing drawings. Sutherland believed that freehand sketching was an intuitive drawing technique that was suitable for the computer. With the use of freehand sketching, it was thought, the user of Sketchpad would be able to capture fleeting ideas and record them on the computer screen relatively rapidly, and that then the computer would resolve the geometric aspects of the drawing through its program.

Although freehand sketching is an important component in developing design concepts in architecture, it is also a valuable drawing aid for engineers to develop and communicate engineering designs. In his dissertation, Sutherland described the new line drawing created in the computer as an appropriate structure for the computer's Cartesian coordinate drawing system. These lines were drawn directly on the computer monitor as if it had some of the characteristics of a sheet of drawing paper. Sutherland developed a "light pen" for interacting on the screen as a hand held drawing tool that resembled a fountain pen in shape and size. Using the rather heavy and cumbersome light pen on the screen's vertical surface was more awkward than the traditional horizontal instrumented drafting board. Sutherland described the Sketchpad line segment as a "rubber band" that is stretched from an identified starting point to an endpoint that is chosen second. Unlike a traditional line which is "drawn" across a surface and retains the character of its making, the Sketchpad line is the straight connection between two points selected with the light pen on the Cartesian coordinate system of the computer screen. A Sketchpad drawing therefore eliminates the relationship between the hand and body of the drafter that existed in the process of physically produced lines.

Shortly after Sutherland's development of Sketchpad as a two-dimensional drawing system, a three-dimensional expansion called Sketchpad III was created by Lawrence Roberts.[38] Curiously, its title, *Machine Perception of Three-Dimensional Solids,* implies the computer shares a human awareness of depth. Its display mimicked the established three –view orthographic projection that is commonly used in technical drawing.[39] Through descriptive geometry the user of Sketchpad was able to accurately represent the shapes of objects in three dimensions on a two-dimensional support such as paper. This drawing system enabled the Sketchpad user to study actual geometric shapes and their characteristics in a graphic visual form.[40] The nature of the Sketchpad system was ideal for descriptive geometry, because in a Sketchpad drawing, "a cross appeared on the computer monitor which could be recognized by the light-pen as the reference and starting point of the drawing. Moving the light-pen in relation to this initiation point allowed one to draw lines in reference to what was being represented on the computer screen."[41] As a result, the dominant Cartesian mentality pervades computer-based drawing. This method was developed without attending to its impact on the architectural imagination. This "mechanized mimesis" too often overlooks how drawing forms the *habitus* of architectural practices, because it is a largely unspoken, shared body of know-how that is intuitively available to architects as they are working out designs through drawing but that is rarely made theoretically explicit.[42] While focusing upon the immediate problem at hand in a design, designers pre-consciously put to use this bodily cognition of using drawing to think. To properly conceive of electronic media in relation to architectural design practices, one must understand not only the outcomes of the tools that precede it and from which electronic media are molded, but also understand the practices by which the activity of drawing is used for conceptualizing.

The majority of applications that evolved from the Sketchpad system were developed to service the engineering needs of governmental institutions and private agencies that prioritized minimizing cost related to labor and construction. By the time architects adopted CAD systems in their profession, it had already taken a defined shape and had minimal capacity to accommodate the architect's unique needs. A design solution is typically selected from among the proposed alternatives of a computer program. Yet it is the nature of computer programs to eliminate many design possibilities and to dismiss design solutions in which it "thinks" the human-user would not be interested. Pioneers in the field of computer science warned designers not to depend on a partnership with the computer during conception because the computer will never be able to match the human imagination in practicing good aesthetic judgment.[43]

Efficiency

The advantages of the symbiotic relationship between the drafter and the computer that was developed in the Sketchpad system were embraced by governmental institutions and private agencies in engineering related drawing programs. Led by the defense industry, these institutions and agencies were financially capable of integrating the early expensive graphical CAD systems into their operations.[44] Mitchell explained that the earliest architectural drawing software resembled the descriptive system of drafting because the funding for developing these programs came from institutions that were interested in engineering-related aspects of building construction.[45]

The development of graphical CAD systems for architectural applications lagged considerably behind those for engineering applications. However, interest in the potential of computer-aided architectural design grew rapidly in the academic community during the 1960's. As computer technology continued to develop, and as costs of these computer systems decreased, it gradually became an increasingly widespread reality in architectural practice during the early 1970's. Yet, these early applications were still mostly related to the process of building construction and included mechanical calculations, cost estimation, economic analysis, and specification production. Funding for the development of computer-aided architectural design programs after the programs that evolved from Sketchpad were from institutions and agencies that were mainly interested in architectural engineering and civil engineering applications.[46] The general approach was inspired by the idea that if the computer could ascertain the intention of the designer from a few quick lines, then it would be able to complete the drawing task and display the outcome rapidly on the computer monitor. Therefore, the drafter would not need to "waste valuable creative time" in resolving all the geometric aspects of a drawing that could be worked out computationally by the computer.

Interest in drafting-room efficiency and mechanization of drawing long preceded computing. Earlier proposals for standardization of architectural drawing were only partially effective, because the individual hand followed its own rules. With computers the natural resistance of hand drawing to "full mechanization" was removed. The shift to automation with computers makes the drafter no longer in control of tools but instead now subservient to the system of production. With automation, increasingly complex tasks are achieved with decreased user engagement, leading to decreased understanding, for the computer's internal operations are invisible and largely unavailable for creative manipulation. Claude Shannon believed that it is the nature of programming to eliminate potential outcomes that do not support the user's data input and to narrow the displayed outcome based on estimating the user's intention. The result is that the output is increasingly predictable, but within a narrower range of possible outcomes. As technique becomes increasingly rationalized within systems, practice is reduced to production through the redefining of theory as technique.[47] This reduces the need for expertise and judgment in practice and the opportunity for ethical, contemplative actions. Shannon warned against using the computer in tasks that were related to aesthetic judgment, because he believed that the human-user will always be superior to the computer in this field and that creativity is limited to the capabilities of the computer program.[48] The human user typically selects a design based on the alternatives proposed by the computer program.

The widespread use of computers in architectural drawing is usually justified under the banner of efficiency. Automated drawing is easily absorbed into larger systems. The much-touted efficiency of computing (the trade name *Revit* derives from 'revise instantly') is rarely critically discussed. For whose benefit is greater efficiency pursued? Likely it is neither for the sake of the design nor the inhabitant. Reducing "mistakes" to be worked out between designer and builder on the construction site also reduces opportunities for discussion and creation of improvements to the design that integrates their shared experience. There is a very real likelihood that efficiency translates into control and profit for the powerful construction industry at the expense of architecture.[49] It is not a coincidence that in the new millennium A/E (Architecture and Engineering) firms are being rapidly acquired by enormous construction conglomerates only after the rise of CAD and BIM. In this new scenario, architecture becomes a small service element of the much larger construction industry. Accordingly, the "industry" is now called AEC (Architecture, Engineering and Construction).[50] While most individuals remain motivated to do "the right thing," the primary criteria are not for architecture, and perhaps not even for the future inhabitants of buildings, but for the construction industry. Architectural practice is now increasingly subservient to the construction establishment in large part because the computer allows unified control over what was earlier by its nature an individual activity. The origin of the computer graphic interface was not intended for architectural use and was the product of slight modifications of engineering CAD tools. Consequently, the symbiotic partner in architectural CAD systems that plays a major role in informing many architects' design decisions today is more equipped to aid engineers than architects.

Inter-Face: Toward Symbiotic Touch

According to Ovid, Pygmalion brought his statue to life through touch. Coming to life in a way that was highly tactile recognizes a deeper, total bodily perception of feeling, like blood flowing through one's veins becoming present on the surface of the skin through sound, warmth and color. [51] This multi-sensorial aspect of space in architecture allows the occupant to appreciate the architectural space without reference to visual input.[52]

Licklider emphasized that between humans and computers "creative, interactive communication requires a plastic or moldable medium."[53] Yet we have seen that the dominant interfaces in use are not made for the architecture profession. Watching a television screen may be a fine way to view movies, but why is it presumed to be the most desirable way to design? To engage the total person of the architect in design the interface must take advantage of much more in the way of human multi-sensorial abilities.

Extended thinking through drawing is a very old architectural practice, and the computer offers such a powerful partnership that it need not be limited to the visual. Clicking on typewriter keys and mouse buttons does not connect one viscerally or palpably with a design question. But the interface as a face-to-face conversation could integrate our larger expressive capacity. As Licklider pointed out at the outset of the computer graphic interface, we need to feel the expression in each other's eyes and hear the tone of voice as much as the words that are written for deeper understanding.[54] He called it a more profound change than the printing press and the picture tube. The opportunities of the computer as a symbiotic partner in design – not just in technology – while largely untapped, remain enormous. As Sutherland suggested, the task of the computer display should be to serve as many senses as possible and not be limited to serving vision. He believed that computer displays of smell, taste and sound would act as powerful tools for the human designer working at the computer.[55]

Denis Diderot, known for the great *Encyclopédie*, in 1765 described a sculpture of Pygmalion: "What softness of flesh; no, this is not marble; press it with your finger and the material which has lost its hardness, will yield to your impression" [56] (Figures 1+2). When we touch the computer, it touches us in return.[57] This could be the basis of a larger partnership in architectural design with computing.

Images

Figure 1. Drawing after Gian Lorenzo Bernini's *Pluto and Proserpina*, 1621-22. (Drawing by D. Kassem)

Figure 2. Drawing after Jean-Léon Gérôme's *Pygmalion and Galatea*, c.1890. (Drawing by D. Kassem)

Figure 3. Robot Maria, *Metropolis*, 1927. (By courtesy of Eureka Entertainment Ltd.)

Figure 4. Robot Maria, *Metropolis*, 1927. (By courtesy of Eureka Entertainment Ltd.)

Figure 5. Sutherland operating Sketchpad on the TX-2 computer at MIT, 1963. (By courtesy of MIT)

Figure 6. Winking Girl (Nefertiti), Sutherland, Sketchpad Dissertation, 1963. (By courtesy of MIT)

Notes

1 Ovid, *Metamorphosis*, Book X, 239f. Pygmalion's statue went unnamed until 1763, when Jean-Jacques Rousseau's opera *Pygmalion* named her Galatea. George Hersey, *Falling in Love with Statues, Artificial Humans from Pygmalion to the Present* (Chicago: University of Chicago Press, 2009), 101.

2 *Metropolis* (1927), with portions restored (Argentina, 2008), Dir. Fritz Lang, Universum Film AG (U.F.A. Erich Pommer).

3 Albert Anthony, "Menacing Technologies: Counterfeit Women and the Mutability of Nature in Science Fiction Cinema," *Fem Spec,* Vol. 5, no. 1 (2004), 1017.

4 Paula James, *Ovid's Myth of Pygmalion on Screen: In Pursuit of the Perfect Woman* (London: Continuum, 2011), 119f.

5 Mircea Eliade, *The Forge and the Crucible, the Origins and Structures of Alchemy* (Chicago, 1978) 29. Architects' tools have sometimes been found interred in the buildings that they designed.

6 Louvre, Paris. See Flemming Johansen, *Statues of Gudea, Ancient and Modern; Mesopotamia,* Vol. 6 (Copenhagen: Akademisk Forlag, 1978).

7 Lon R. Shelby, "Medieval Masons' Tools. II. Compass and Square" *Technology and Culture* 6, no. 2 (Spring, 1965) 236-248. Maya Hambly, *Drawing Instruments, 1580-1980* (London: Sotheby's, 1988). H.W. Dickenson, "Ancient Drawing Tools" *Transactions of the Newcomen Society* 27 (1949-51), 73-83.

8 Joseph Rykwert, "Organic and Mechanical," *Res: Anthropology and Aesthetics* 22 (Autumn, 1992), 11-18.

9 Vitruvius, 10. 1. 3, transl. Richard Schofield, *Vitruvius on Architecture* (London: Penguin, 2009), 278.

10 R.T. Gunther, ed., *The Architecture of Sir Roger Pratt* (New York: Benjamin Blom, 1972).

11 Martin Heidegger, *Being and Time*. James J. Gibson, "The Theory of Affordances" in *Perceiving, Acting, and Knowing*, edited by Robert Shaw and John Bransford (1977).

12 J.D. North, "The rational behavior of mechanically extended man" (September, 1954), cited in Licklider, "Man-Computer Symbiosis" p. 2. Ivan Illich in David Cayley, *The Rivers North of the Future: The Testament of Ivan Illich as told to David Cayley* (Toronto: Anasi, 2005), 162. Giorgio Agamben, *What is an Apparatus?,* David Kishik and Stefan Pedatell, trans. (Stanford University Press, 2009), 15.

13 J.C.R. Licklider and Robert Taylor, "The Computer as a Communication Device," *Science and Technology* (April 1968), 21-41.

14 Doron Swade, *The Difference Engine: Charles Babbage and the quest to build the first computer* (New York: Viking, 2001).

15 Joseph Carl Robnett Licklider, "Man-Computer Symbiosis," *IRE Transactions on Human Factors in Engineering*, Vol. HFE-1 (March, 1960), 4-11.

16 Licklider, "Man-computer symbiosis," 1960, 9.

17 Licklider and Taylor, 1968.

18 Donald Michie, *The Creative Computer: machine intelligence and human knowledge* (New York: Viking, 1984), 17.

19 Russell Morash, "Computer Sketchpad," in *Science Reporter*, Lowell Institute Cooperative Broadcasting Council, ed. (Cambridge: MIT, c. 1960s).

20 Licklider, "Man-Computer Symbiosis," 4.

21 Biological mutualism is any relationship between individuals of different species where both individuals benefit. Some symbiotic relationships are obligate, meaning that both symbionts entirely depend on each other for survival. Others are facultative, meaning that they can, but do not have to live with the other organism. Licklider seems to imply an obligate relationship between human and computer, though he also qualifies it with a mutualist relationship.

22 Ivan Sutherland, *Sketchpad: A man-machine graphical communication system* (Cambridge: MIT Dissertation, 1963), 8.

23 Licklider, "Man-Computer Symbiosis," 4.

24 Claude Shannon, *Claude Elwood Shannon: collected papers*, N.J.A. Sloane, A.D. Wyner, eds (New York: IEEE Press, 1993), 691.

25 Christopher Alexander, *Architecture and the Computer; Proceedings of the first Boston Architectural Center Conference* (Boston, Mass.: Boston Architectural Center, 1964), 52.

26 Ingeborg Rocker, "Interface: Between Analog and Digital Systems" in *LIFE information, on Responsive information and variations in architecture: Proceedings of the 30th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)* (New York: Cooper Union, 2010), 53. Don Ihde, *Bodies in Technology* (Minneapolis: University of Minnesota Press, 2002), 97-8.

27 Richard Noakes, "Instruments to Lay Hold of Spirits: Technologizing the Bodies of Victorian Spiritualism," in *Bodies/Machines,* Iwan Rhys Morus, ed. (London: Berg, 2002), 125-163.

28 Nicholas Negroponte, *Being Digital* (New York: Vintage, 1996), 103.

29 Licklider, "Computer as a Communication Device," 1968, p. 21.

30 Clifford Geertz, "Thick Description: toward an Interpretive Theory of Culture" in *The Interpretation of Cultures: selected essays* (New York: Basic, 1973), 6.

31 Sutherland refers to his drawing of Nefertiti as "cartooning." Sutherland, 107. Her appearance and winking are also comparable to the famous early cartoon character Betty Boop. Invented in 1930 and still well known, her flirtatious wink is famous and the phrase "made of pen and ink, she will win you with a wink" introduced Betty's cartoons. Like Sutherland's winking cartoon girl, Betty Boop ruptured divisions between reality and representation.

32 Earl Ertman, "Nefertiti's Eyes" *Archaeology,* Vol. 62, no. 2 (March/April 2008), 28-32.

33 Albert Anthony, "Menacing technologies: Counterfeit Women and the Mutability of Nature in Science Fiction Cinema," *Fem Spec,* Vol. 5, no. 1 (2004), 1-17.

34 Telephone Interview with Ivan Sutherland, Dalal Kassem, 2013.

35 Licklider, 1960, p. 9.

36 Karen Frenkel, "An interview with Ivan Sutherland," *Commun*. ACM 32, no. 6 (1989), 712-3.

37 Le Corbusier, *Toward an Architecture*, trans. John Goodman (Santa Monica: Getty Research Institute, 2007), 92.

38 Lawrence Roberts, *Machine Perception of Three-Dimensional Solids* (Cambridge: MIT Dissertation, 1963).

39 John Rule and Steven Coons, *Graphics* (New York: McGraw-Hill, 1961).

40 Riccardo Migliari, "Descriptive Geometry: From its Past to its Future," *Nexus Network Journal* Vol. 14, no. 3 (2012), 555.

41 Rocker, 56.

42 "Mechanized mimesis" is a term coined by Mario Carpo, cited in Daniel Estévez and Gérard Tiné, "Project and Projections: Some advantages of the principle of opacity" in *Perspective, Projections and Design: Technologies of Architectural Representation*, Mario Carpo and Frédérique Lemerle (London: Routledge, 2008), 163-4. Paul Emmons, "Demiurgic lines: Line-making and the architectural imagination" *Journal of Architecture* Vol. 19, no. 4 (2014), 1-24.

43 Licklider.

44 Norman Sanders, "An Industry Perspective on the beginnings of CAD" *SIGCSE Bulletin*, Vol. 40, no. 2 (June, 2008), 128-134.

45 William J. Mitchell, *Computer-aided Architectural Design* (New York: Van Nostrand Reinhold, 1977), 15.

46 Mitchell, ibid., 16.

47 Alberto Pérez-Gómez and Louise Pelletier, *Architectural Representation and the Perspective Hinge* (Cambridge: MIT Press, 1997), 174.

48 Claude Elwood Shannon, *Claude Elwood Shannon: collected papers*, ed. N. J. A. Sloane, A. D. Wyner, and Ieee Information Theory Society (New York: IEEE Press, 1993), 691.

49 Daniel Bell, "Work and its Discontents: The Cult of Efficiency in America" in *The End of Ideology* (Glencoe: 1960). Anson Rabinbach, *The Human Motor, Energy, Fatigue and the Origin of Modernity* (New York: Basic, 1990). Michel de Certeau, *The Practice of Everyday Life*, trans. Steven Rendall (Berkeley: University of California Press, 1984), 175-6. The rationalization of construction documents is sometimes translated into the absurdity of building the drawing.

50 *Mastering Revit* (2010), 5.

51 George Hersey, 95-6.

52 Marco Frascari, *Eleven Exercises in Architectural Drawing* (London: Routledge, 2012).

53 Licklider and Taylor, 22.

54 Licklider and Taylor, 23. Face to face communication allows externalizing models so people can be sure they are talking about the same thing.

55 Ivan Sutherland, "The Ultimate Display" (paper presented at the Proceedings of IFIP Congress, 1965).

56 Diderot, 1765, quoted in Hersey, 97.

57 Negroponte, 133-4.

About the Authors

Paul Emmons is a registered architect and professor at Virginia Tech, where he directs the PhD program in Architecture and Design at the Washington-Alexandria Architecture Center. He earned a PhD from the University of Pennsylvania, a Master of Architecture from the University of Minnesota, and has widely published on architectural drawing practices.

Dalal Kassem is an architect and has been teaching at Kuwait University since 2008. After receiving her architecture degree from Kuwait, she earned a Master of Architecture from the Illinois Institute of Technology in 2010. She is currently at the Washington-Alexandria Architecture Center of Virginia Tech, where she is completing her PhD dissertation on the first computer graphic interface.