# Computational Design: Design in the Age of a Knowledge Society

Formdiskurs


Knowledge is becoming increasingly computational. Previous means and methods for the acquisition, communication, and criticism of knowledge are being replaced by inquiry, dissemination, and evaluation carried out by digital means. Pascal, Leibniz, and Peirce, among others, prepared the conceptual framework for this fundamental change. They asked questions regarding our motivation to know, our way of acquiring knowledge, and our desire to share it. In other words, they defined the cognitive horizon. Closer to our time, Boole, Wiener, and von Neumann provided the scientific foundations. Finally, Atanasoff, Zuse, Eckert and Mauchly (among others) built the machines. The rest is already part of our lives: computer graphics, visualization, desktop publishing, CAD, multimedia, virtual reality, Internet, World Wide Web – with more to come. In the process, sciences became computational: physics, biology, chemistry, to name the best known. Many engineering endeavors took the same turn with the synthesis of materials, robotics, even the production of computers, and the automatic generation of software. What happened to design in this context of fundamental change?

**A snapshot of the current situation**

As things stand, computers and design are merely an association of tools and users. Indeed, within the design community, the discussion still goes on whether the computer will ever replace the designer, or if it will at least replace the pencil and the marker, not to mention the tedious process of model building. Graphic designers are very much ahead of the rest, plowing happily in the new territories of typeface design, print on demand, and electronic publishing. They discovered very quickly that digital technology means not only better tools for old functions, but also a broadening of the scope of their activity. The laser writer, the scanner, the plotter, the compact disk, and more recently network tools (browsers, applets, frames) were integrated in a new practical effort. So were the methods and means of science – sampling, splicing, mutations, hyperlinking. As a result, printed paper is complemented by multimedia and Internet-based communication. Exemplary of the effort I am referring to is also the new practice of communication design: the virtual design office. Indeed, in this case designers designed their own new context of interaction based on the technologies and the methods they work with. Thus the computational becomes constitutive of the work, and is tested as the work itself is subjected to evaluation. But even in graphic design, fundamental issues are still avoided: Do we address a generic human being, who has remained the same as science and technology have changed? Or do we "design" our own public, i.e., invent forms and means for more individualized, and still socially rooted, forms of human interactions? How do we transcend the dominant obsession with mass communication (broadcasting) and make narrowcasting a design goal equally significant in respect to contents and expressive means? Do we improve on what we inherited or do we participate in the renewal of the motivations and means of communication?

Technology, even as it is creatively applied in communication design, is still ahead of us. In other design activities, and primarily in what is called product or industrial design, the situation to date is less promising. While the old-fashioned industrial design practically stopped generating employment opportunities, educational programs are slow in acknowledging the need for integrating the digital. The educators involved still think in the solid terms of the model of the Industrial Revolution, terms that are based on formal expectations of crafting but not on the need for new design thinking. As we know, the investment in technology – hardware, software, maintenance, training, research of new avenues – is prohibitively high. Few have dared to take the risks of entrepreneurship, and even fewer have succeeded. Big companies consolidated their controlling positions, and literally sucked in everyone able to manage the complexity of computer-based or computer-aided design. In many cases, instead of making design more transparent, they insulated themselves under the very convincing argument of protecting intellectual property instead of disseminating it. It is not unusual that advanced product design teams using advanced computers and sophisticated software do not even have access to the Internet. While those involved in digital technology attempt to produce viable methods of cooperative design work, such teams are predicated to a monastic type of activity. More often than not they do not even notice the contradiction between the means used and the methods and structures of work. Consequently, they maintain the secrecy (of new car models, new toys, new furniture, etc.), but are always late on the market.

Technological lead over design considerations is radical not only in the area of industrial design. It is also manifest in textile, fashion, toy, and interior design, all forms of design still close to the paradigm of craftsmanship. Consequently, monstrosities of all kinds, conceived with the aid of some computer programs, spill over to the consumer in the supermarkets of discounted bad taste. No matter how "noble" the intention of making affordable every gadget that until now was in the exclusive realm of the military and the intelligence communities, it only rarely justifies their presence in our culture.

**About the possibility of design theory**

Computational design acknowledges the association between tools and users. However, its goal is to turn this into an association of new possibilities, which should become realities through design. To achieve this goal, computation cannot be only, as it is today, a medium of representation and unsystematic, or even systematic, variations. It has to become constitutive of design. This brings to the forefront the older question of whether design theory is possible, and if yes, which form it can take.

In the past, to the extent it was formulated, theory has followed the practice of design. The best designers, or at least those able to articulate their thoughts in writing, rationalized their achievements; that is, they discussed what they did and how only after their design was acknowledged or received public acclaim. This situation should not surprise anyone. Design evolves, as we all know, from the crafts and in this evolution, it first has to acquire legitimacy among many other human endeavors. But as it develops its means and methods, it also produces its justification and conceptual horizon. With the emergence of design criticism and design history, obviously in connection with the establishment of design education, the possibility of theory is established. Such a theory had to be analytical at the beginning. In time, induction – acquisition of knowledge through observation – was complemented by deduction – derivation of new knowledge from design generalizations. As a result, design theoreticians were able to venture into synthesis. The example of the Russian Constructivists, or of the Bauhaus, or of American design after World War II belong to the domain of new concepts. Some were adopted from morphology, structuralism, semiotics, and even from psychology, linguistics, sociology, and engineering. Others were derived from within, the best example being functionalist design. In recent years, algorithmic thinking, heuristic procedures, and even genetics found their way in the theory of design. Moreover, design hypotheses were computationally modeled and tested. My own Design Machine™ can be mentioned as an example in this direction.

Theories attached to discursive reasoning remain captive to the deterministic equation: there is a cause, i.e., design work, and there is a result, i.e., designs that become identifiable objects traded or culturally recognized for their characteristics. So it ought to follow that a theory should explain how people design and what good design is. Here things get murky. First of all, because language as we know it might be the best medium for our reciprocal understanding, but not necessarily for handling human activities that by their nature are not reducible to language. Second, because the romantic assumption within discursive reasoning is that good design – "good" being defined in a given context (formal, functional, structural, etc.) – is also successful. Obviously, a good design theory should explain why sometimes this is not the case. As this kind of questioning in and with the help of language is established, we have learned that design theory is inter- and transdisciplinary. These are good words to use in applying for a grant, but not necessarily helpful in practicing design theory, or in designing. Nevertheless, the result of this understanding explains the import of specialized language in design. Ergonomic, functional, psychological, sociological, and economic concepts invade the dialogue on design issues and the curriculum of design education. Designers speak to future clients more about ergonomic, cultural, or symbolic aspects than about design itself. More recently, the language of lawyers is being added to the wholesale package of design theory, since the practice of design also means protecting its products in a society inclined to protect the written, but not necessarily the more ambiguous visual expression.

**A design knowledge base**

Computational design escapes this Catch-22 situation. It is, like any other form of computational knowledge, anchored in the pragmatics of human existence. As we know, computational physics is at the same time theory and practice. As theory, it produces hypotheses regarding the beginning of the universe, for example. As practice, it simulates them in order to test the validity of the premise, and it eventually transforms them into new tools for the investigation of the universe. Simulations serve further to derive new knowledge regarding our inquiry of the universe. They also help us to understand the meaning of this knowledge for our own activity, regardless of whether we are physicists or professional involved in other fields (biology, chemistry, philosophy, art). Such knowledge is proactive, in the sense of opening new avenues for practical endeavors. Think about the many experiments with plants, animals, food or even with art performed in outer space. Computational engineering synthesized new materials – some very interesting for designers – and as a result also opened new avenues towards the future. It starts from hypotheses at the molecular or atomic level. Its results are the new structures modeled and tested in computational form before any other natural resources are processed. Computational genetics is a practical activity having at its center human well-being.

Computational design means, then, design activity driven by the forces that make design possible and necessary in the first place: assessment of needs, assessment of possibilities, assessment of means as they embody human characteristics. The assessment takes the form of data, in particular, complex databases. But while any other design theory is by its nature reactive, based on opinion, and thus often speculative, a computational design theory is based on processed data and is by its nature proactive. Its limits are the limits of our ability to collect and meaningfully organize data regarding quantity as well as quality, and our ability to design effective computational procedures for their processing. Like any other computational theory it is at the same time practice, more precisely design practice in the broader context of extremely differentiated forms of human activity, such as those we experience today. It is subject to confirmation by test, and it is, first of all, centered on knowledge, the most important asset human beings have. Accordingly, it requires that we establish a design knowledge base that extends beyond the poor, or even less than poor, design museums and collections, books and articles about design. Furthermore, it requires that we design procedures for navigation, search, and retrieval in such a knowledge base, evidently conceived at the global level of human existence today. Artifacts, along with the plans and designs from which they were derived, need to be seen together from a broad cultural perspective. Such a knowledge base should also contain computationally expressed knowledge regarding visual representation, movement, color, ergonomy, the integration of other means of communication (sound, texture, smell, etc.). All these objectives are a tall order, but unavoidable. Unfortunately, the majority of our design museums and collections, the places where we look at design as a “school of the past”, resemble a junkyard more than a knowledge base for design.

As examples of what belongs in our design knowledge base, as it started to become a reality, are the computer programs that the design community uses. Indeed, a CAD program, or one for the production of a new font, a multimedia composer, or a net browser is already a theoretic expression of high abstraction. Within such a program, we describe geometry, material characteristics, optics; we describe movement, perspective, associations of images and sounds, ways to integrate text, and many other components of design. Not all of them are captured together in such programs, of course, but at least those about which a design consensus has been established. Or those we understand better. The practice of design based on such “theories” is, then, the research of actual design assignments. And the evaluation of the design is the performance of the artifact digitally conceived. In successive versions, benefiting from the experience of design such programs improve. As I write these lines, Netscape™ 3.0 is being announced; it will integrate teleconferencing, which makes my next statement self-explanatory. In the succession of design hypotheses, some disappear because the theory they advance proved inappropriate. Only two years ago, teleconferencing, a major communication design idea, was a potential multibillion dollar market. In our days, it is becoming a standard browser function.

Let me make the idea of design as program more clear: The Macromedia Director™, or the Phontographer™, or Alias™, or Vellum™, or those programs used for desktop publishing (Quarkexpress™, Pagemaker™), for textile design, for jewelry, etc., are programs we can buy in stores and use for particular jobs. But as opposed to the pencil, brush, exakto knife, wood or metal type, composer stick, etc. that designers used in the past, such programs are condensed theories of the activity they support or invent (as was the case of teleconferencing). None describes design completely. They describe and synthesize design activities related to our interest and need for multimedia, font design, or for CAD, for publication design or for on-line advertisement. Those who authored such programs, quite often large teams of programmers, psychologists, designers, etc. integrate in them knowledge of physics, mathematics, aesthetics, semiotics, of ergonomy, etc. In fact, each such program is a theoretic hypothesis. Those using them test this hypothesis. The products that are finally generated are comparable to the products that result after computational engineering is applied for creating new materials, or computational genetics for creating new medicines.

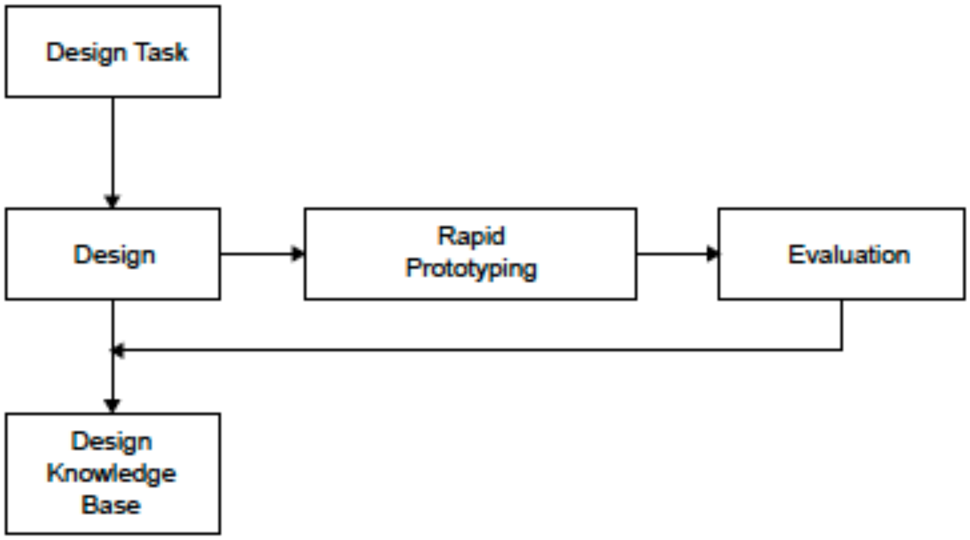
**Computers are NOT only tools**

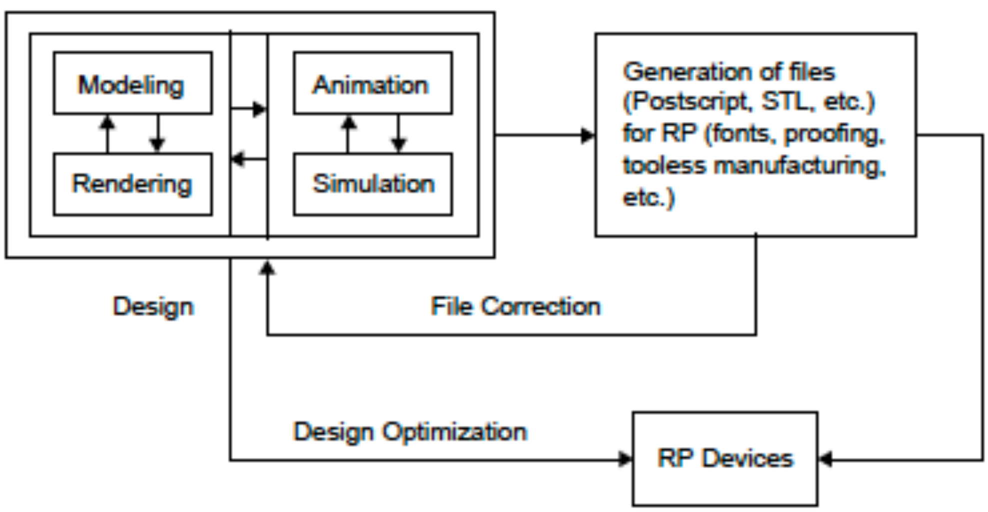
In fact, new materials, new medicines, and new genes are designed. I use this term to suggest that design is becoming a very broad endeavor in the age of computation. If we do not understand the necessity of computational design, we only continue the metaphysical talk about how computers are only tools. Or we continue the poetic description of how design originates, like Venus from the head of Jupiter, in the head of designers. Or how intuition explains what indeed some programs still cannot achieve, not because they do not have intuition (which they don't have to have), rather because in using them, we are not yet as comfortable with them as to use them creatively.

Let's face it: many aspects of design can be carried out perfectly without any use of computers. Such aspects are not really the object of computational design. After all, computational design does not replace design, it continues and broadens design in a new pragmatic context. The real challenging aspects of design in our times are exactly in the realm where without the new design knowledge in its computational form, we could not come to viable solutions. Consider the design of the Hubbell telescope, and consider further its fixing, after it was launched in a defective state and started its journey around the earth. It was in a computational design model, involving means and methods of virtual reality, that the design error that almost rendered the telescope useless was diagnosed and procedures for improvement, including design of tools appropriate to the task at hand, generated. This is why computational design integrates modeling, rendering, animation, but also simulation (including virtual reality). That this level is only timidly reached should not prevent us from understanding that the digital model resulting from a comprehensive computational design work is infinitely more telling than the Styrofoam, or wood, or polymer 3D artifacts that so many continue to idealize. As conversational pieces, models convey a beautiful quality of immediateness. However, for the production of the real objects, they are as poor as any reduction of the real to a model. Moreover, the emerging rapid prototyping is far ahead of any other modeling endeavor. Whether driving CNC tools or even performing modest stereolithography, computational design allows a designer to reach a level of evaluation that is not possible in the mechanic's shop. Instead of hiring a good carpenter, as some designers and architects still do, we can perform, even today, remote prototyping either in the form of virtual reality or in physical 3D. Design and tools can be connected via networks.

**What is a prototype?**

In order to clarify the design implications, let us start with a conceptual framework. To design is not to make the "real" thing, but the prototype of what will become, for example, a newspaper, a bicycle, a new fashion line. In previous times, when production cycles were long, design cycles were also relatively long. This situation has changed. We live in a day-and-age described by "just-in-time" or "time-to-market." From concept to shipment and distribution, time has been reduced by many orders of magnitude. The design process and the fabrication process are interdependent. With the risk of some simplification, generic diagrams give an idea of the process:




Rapid prototyping – everything following the design phase – as a computational component, deserves at least some words of explanation. First of all, graphic designers were again in the forefront since they started “rapid prototyping” by using digital technology for proofing and pre-press evaluation. Service bureaus all over the world perform, remotely, everything from typesetting to color correction and pre-press functions – all that it takes for a design to make it from the “artist” to the client. In recent years, textile prototyping on “virtual looms” became possible and rapid prototyping service bureaus for product development started opening, too. The San Diego Supercomputer Center supports remote prototyping on the Internet.

Sure, prototyping in 3D, for industrial design purposes, is a more complex enterprise than proofing for communication design, of for textile design. We know how to generate good postscript files to drive laser printers, for example. But we are far less good in generating the so-called .STL files that drive RP devices. Such files employ a surface representation defined by triangles and serve in the fabrication of 3D models. RP technology started as a subtractive process – a numerically controlled (NC) machine chiseled away, pretty much like a sculptor does working on marble or wood, what was not necessary. Today it offers additive mechanisms in the form of stereolithography (liquid photopolymers solidify under the appropriate light), selective sintering (the fusing together of thermoplastic powder by using a laser beam), droplet deposition (laying down of an adhesive liquid over a thin layer of ceramic or metal powder). We even have a combination of additive and subtractive processes, such as in fused deposition modeling (the melting of a thermoplastic material and its further "printing" in the designed form) and laminated object manufacturing (a laminated object is processed from layers of paper).

Obviously, designers do not have to be experts in thermoplastic fusion or in stereolithography. But they need to think in terms of computer-aided design (CAD) and rapid prototyping (RP), because the connection between representation (in design) and actual fabrication (through computer-aided manufacturing – CAM) is getting tighter. Moreover, they need to realize that due to such technology, design tasks shift from the traditional expectation of *giving form*, of *Gestalt*, to inventing new forms, some as exotic as the design of new molecules, new genes, new materials, new forms of human interaction. Indeed, in the computational design context, aesthetic considerations and functional characteristics need to fuse. In order to accomplish this goal, designers can no longer restrict themselves to being agents of order and beauty, leaving the "dirty job", as to how things work, to engineers.

Having mentioned the word *idealize* in reference to the nostalgic view some designers still have, I need to confirm that, in effect, the digital model is in the realm of the ideal, where characteristics are simulated and can be optimized by varying many parameters. Some see here the shortcoming of computational design, although it is its strength. In the past, models could only display characteristics of available materials. Computational design models make the question of appropriateness of materials possible. They challenge the designer to go beyond what is available. Those who feel insecure about the ideal nature of the digital representation fail to realize that the majority of human activity is in the ideal domain of the cognitive, not in the necessary, but somehow limiting training of skills (quite often on machines and tools of yesteryear).

**Design and anticipation**

The strength of the human being, as a creative entity, is in anticipating, not in reacting to the outside world and its natural changes. Computational design is by its nature anticipatory, proactive. In other words, it addresses a conceptual realm defined by the fact that the current state of a system depends on its future. At first, the thought sounds dubious. It brings to mind predestination, or teleology.

But once we consider the idea, we understand that without the planning element, which is anticipation, design remains a catch-up game, a form of reaction to change, instead of being an agent of change. Design as problem solving, the slogan of a deterministic past so close to us that we are not sure whether we have overcome it, was such a game. In contrast to continuing the line of a practice of re-packaging (all the series of coffee machines, toasters, cars, radios, and computers, based on the same components but stylized differently), computational design involves and supports invention. It challenges the once-and-for-all solution, especially in view of an increased ecological awareness. It generates problems as it takes an active role in repositioning the individual in our environment and in an extremely dynamic social life. It does justice to the individual and to the particular context of existence as it brings mass production to an end and facilitates customized solutions. To explain this component, I need to briefly revisit previous pragmatic contexts.

Pragmatic contexts correspond to specific forces at work, energy sources tapped, social and political structures. The prehistoric hunters and foragers had design needs and expectations very different from those of the humans involved in agriculture and animal husbandry. Craftsmen and factory laborers, even in our day, relate differently to design as it defines their living environment and their work than do teachers, physicians, scientists, artists. The Industrial Revolution posed many design problems. It also broke the world into many unrelated pieces. Think of all the appliances in one's home, or of the many tools in our offices and factories. Each makes up a world in itself, with its own rules for performing appropriately. The information age brings about the possibility of integration. Issues of energy consumption, environment, and better human interaction, issues of cultural diversity can be better addressed if we design with the aim of integrating human tasks without ignoring the differences among people living under different conditions. Computational design should accordingly constitute the conceptual framework for such a task and become the practice of accomplishing it. Evidently, as integration takes place, we have problems in dealing with complexity. More buttons and more keys, no matter how elegantly designed, do not help in our command of the new complex machines. Accordingly, designers need to work on giving through design a better control of complexity. Otherwise, each wonderful new machine will only be used to 20 percent of its actual capacity – which is the situation today. Design stuck on formal considerations does not effectively help users get the most out of what is technically possible today.

**Design and ubiquitous computing**

The expansion of computation – through networking, which contributes to the dynamics of the global economy, and through ever increasing performance – parallels the deployment of electricity as it took place earlier in the 20th century. Electricity, telephony, and television form an integral part of the underlying structure in many parts of the world. Similarly, millions of people already benefit from digital interaction through networks and from the progressive integration of computation in human transactions of all kinds. Computation is integrated in the telephone, in many services associated with wireless communication, in wristwatches, in home appliances, in trucks and automobiles, in airplanes, in automatic teller machines, in entertainment and edutainment. Compared to the state of computation, the creative use of digital technology is only at its beginning. Computational design should assume the goal of actively speeding up the process. It is irrelevant whether one or another designer decides not to use the computer. The dynamics of the process is such that the broader change does not depend upon such decisions. Many designers resisted the change announced by the desktop publishing programs of yesterday. As primitive as some of these programs were, and some failed in the meanwhile, they opened a new horizon and led to a reality expressed in the simple fact that those who do not master such a program cannot find a job in the design industry. Forces at work, characteristic of the global economy, define further directions which, if acknowledged and properly understood, allow for more variety and the unfolding of more possibilities. The underlying dimension of computational design is optimism.

The new tasks of design in the context of the fundamental change we are experiencing result from the recognition of the new fundamental pragmatic condition of the human being. The tasks of design education cannot be less affected by this condition. Therefore, to practice design and design education*proactively*, not merely in reaction to technological developments, means to make the medium of computation, and any other information processing medium, part of design. In short: not that books, posters, brochures, or cars, toasters, chairs, and lamps are invalid design subjects, in the studio or in college education. Rather, knowing only how to design such items does not prepare a designer for those qualitatively new problems we are facing. To use the computer for design cosmetics, doing what traditional tools can do just as well, is unproductive and unsatisfying. The computer has to be creatively integrated in the design process, in the new products designed. This is something the computer industry does not know how to do but is trying desperately to achieve. Those who work in the computer industry know that faster chips, more storage capacity, and better compression schemes are only means to a goal that is fundamentally in the realm of design. Accordingly, computational design will make designers become partners in the ubiquitous computing revolution.

The functionalist thought is echoed in the ubiquitous computing design program. Instead of the bulky machine on everyone's desk, and instead of turning each user into a typist, ubiquitous computing offers the perspective of natural interaction with many "invisible" digital devices. It replaces the obsession with better interfaces, as a hope for better user performance, through integration of computer capabilities in appliances and tools that do justice to the human being and to the task at hand. A computer isolated from the task at hand requires excessive attention. Once reconnected to the purpose, digital technology enhances our ability to fulfill the purpose. The integration of information processing capabilities in ways that complement people's abilities and their ways of thinking is a major goal of computational design. In order to benefit from the electric bulb, one does not have to learn how a power plant works, even less how to operate a high voltage transformer. The same should be the case for people using active maps to obtain weather reports, travel assistance, or tourist information. Or for those using the new washing machine that integrates fuzzy logic computing. New products – cars, VCRs, furniture – that "learn" the behavior of the user, hospital equipment that assists the nurse as well as the patient, intelligent tools of all kind, should not require a college degree to operate. Computation should fit us as comfortably as a pair of sneakers. And we should be able to use it when necessary without having to study volumes of printed matter or to go through extensive training. That interface design is a major aspect of computational design should be obvious. Less obvious is the fact that the best interface design, like design itself, is invisible, i.e., integrated in the object or message designed. These are goals that define design tasks in a context of fast technological renewal.

**Design research: a force for change**

With the advent of computational design, design enters a new phase of its remarkable history. As a participant in the establishing of a new pragmatic framework for human activity, design innovation makes possible distributed work. Accordingly, it contributes to decentralization, and to the disappearance of hierarchic structures. Within the design community such changes already take place, not always as smoothly as we would hope for, but definitely with the effect of a higher sense of responsibility. Much more will take place, and probably even more painful changes will affect the profession as it seeks its justification in a society determined to achieve levels of efficiency high enough for the sustenance of the global economy. As we reach the time when the rate of change equals that of innovation, designers are forced into the forefront. This is why procrastination, a survival tactic in times of less fast change, will not do. This is also why means and methods not adapted to these fast cycles of change fail. The bad news is that in the competitive context of today's world, the bankruptcy rate in design is higher than ever. The good news is that more and more innovative designers, definitely aware of computational design or practicing it in some form or another, make their way in the competitive market of innovation and become icons in the process. Where yesterday in Greenwich Village were the gadget shops, today design shops offer a variety of services based on new media, new materials, new forms of human interaction. By no accident are the designers of business cards and stationery replaced by coin-operated machines placed in hotel lobbies, bus depots, and train stations. New design addresses our minds more and more. Maybe a Website for an individual is not the highest goal one can have, but to think in terms of human interconnectedness and cooperative effort is of a higher order than to stylize cars, lamps, or to produce idiotic messages on postcards for illiterates.

With the advent of computational design, design finally defines its own domain of research and development. As a result, instead of waiting for other disciplines to define its agenda or scope of inquiry, computational design makes design research a force of change.

**References**

The following are references for persons, concepts, and ideas used in the text.

Boole, George. (1815-1864) conceived of a logical calculus in *An Investigation of the Laws of Thought on which are founded the Mathematical Theories of Logic and Probabilities* (London, 1854)

von Neumann, John, the legendary mathematician, was also instrumental in the paradigm of sequential computing. He was aware of the ENIAC (Electronic Numerical Integrator and Calculator) built by J. P. Eckert and John Mauchly) and in 1945 wrote the famous *First Draft of a Report to the EDVAC* (Electronic Delay Storage Automatic Computer).

Wiener, Norbert. *Cybernetics*. Cambridge MA: MIT Press. 1948

Regarding the Design Machine (a research project carried out in 1985-1988):
Nadin, Mihai, Marcos Novak. MIND – A Design Machine, in *Intelligent CAD Systems*, Vol. 1 (Ten Hagen, T. Tomiyama, Eds.). Berlin/New York: Springer Verlag. 1987

Regarding Anticipation:
Nadin, Mihai. Mind – Anticipation and Chaos (German-English parallel text, from the series Milestones in Thought and Research). Stuttgart/Zürich: Belser Verlag. 1991. Develops a cognitive model based on chaos and anticipation.

Rosen, Robert. *Anticipatory Systems*. Philosophical, Mathematical & Methodological Foundations. Oxford/New York: Pergamon Press. 1985