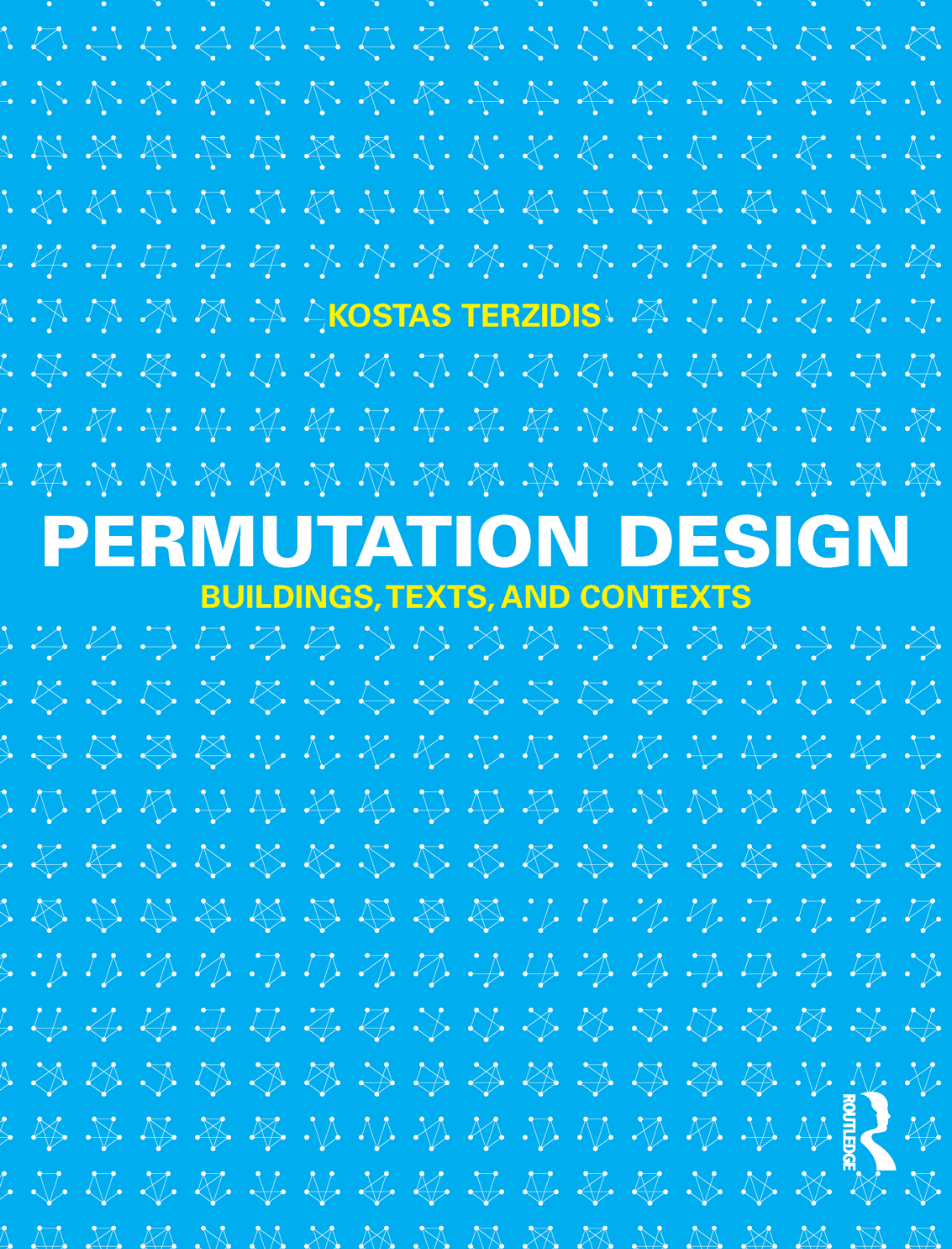

KOSTAS TERZIDIS

PERMUTATION DESIGN

BUILDINGS, TEXTS, AND CONTEXTS

ROUTLEDGE

Permutation Design

In design, the problems that designers are called upon to solve can be regarded as problems of permutations. A permutation is an ordered arrangement of elements in a set. In our case, the set is design and the elements are design components, such as lines, shapes, forms, or spaces.

Traditionally, such arrangements are done by human designers who base their decision-making process either on intuition or on random sampling until a valid solution is found. However, in both cases the solution found may be an acceptable one but cannot be labeled as "the best possible solution" due to the subjective or arbitrary nature of the selection process. In contrast, by harnessing the potential of computational design, these elements can be arranged in all possible ways and then the best ones can be chosen based on specific criteria. By presenting a complete list of permutation-based arrangements the "best solution" will eventually reveal itself by excluding all other possible solutions.

This book comprehensively addresses theories, techniques, and examples of permutation design in order to fully demonstrate to the reader the full range of possibilities this method represents. The significance of such an approach to design is enormous, paradigmatic, and far-reaching. It provides an alternative method for design analysis, synthesis, and evaluation that is based on computational force rather than pure human intelligence alone. In contrast to human-based random sampling or intuition, permutation-based design offers the assurance of an optimum design since any possible alternative design can be eliminated. From a practical point of view, this methodology offers a paradigmatic shift away from the current state of design practice where arbitrariness, repetition, and redundancy often exist. From a theoretical viewpoint, this new paradigm may offer alternative insights into the value of human creativity, intuition, and intelligence.

Kostas Terzidis was an Associate Professor at Harvard University Graduate School of Design from 2003 until 2012. He taught courses in Algorithmic Architecture, Kinetic Architecture, Digital Media, and Design Research Methods. He holds a PhD in Architecture from the University of Michigan (1994), a M.Arch from OS (1989), and a Diploma of Engineering from the Aristotle University in Thessaloniki, Greece (1986). He is now the CEO and co-founder of Organic Parking, a company developing smart city parking space optimization using mobile social networks.

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Permutation Design

Buildings, Texts, and Contexts

Kostas Terzidis

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2015
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
711 Third Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
Terzidis, Kostas, 1962-
  Permutation design : buildings, texts and contexts / Kostas Terzidis.
    pages cm
  Includes bibliographical references and index.
  1. Architectural design—Data processing. 2. Decision making—
  Data processing. 3. Computer-aided design. I. Title.
  NA2728.T475 2014
  720—dc23 2014001460

ISBN: 978-0-415-64449-5 (hbk)
ISBN: 978-0-415-64450-1 (pbk)
ISBN: 978-1-315-79591-1 (ebk)

Typeset in Minion
by Keystroke, Station Road, Codsall, Wolverhampton

To my mother, Ismini,
for challenging my certainties

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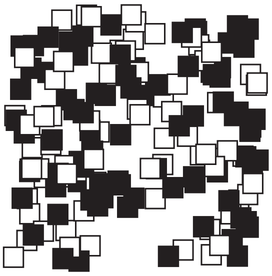
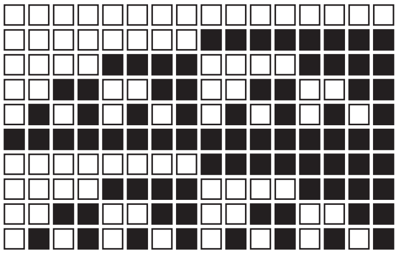
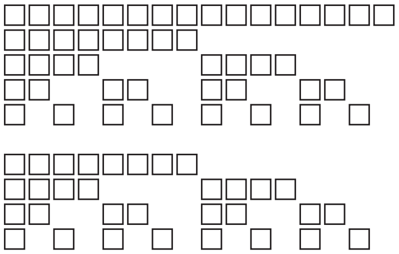






Introduction

DESIGNERS and artists express their ideas by developing imaginary worlds before they project them as images on a drafting board or a canvas. In their minds, they create an ideal world, a world that fits their needs and expresses their desires. By creating systems of symbols and rules, designers are able to describe, represent, and control their imaginary worlds. In architecture, for instance, the construction and development of significant buildings was usually preceded or paralleled by theoretical projects which were never built, either because they were too impractical or because their purpose was to be used as ideal models and paradigms to be followed. By formulating such models, theorists were able to express their theoretical views about architecture, space, and society, to criticize the current practice, and to demonstrate how they imagine an ideal world. Perault, the architect of the peristyle of the Louvre, argued that architecture is a fantastic art of pure invention.[1] He asserted that architecture really exists in the mind of the designer and that there is no connection to the natural world. In addition, architecture as an imaginative art obeys its own rules which are internal and personal to each designer, and that is why most creators are vaguely aware of the rules of nature and yet produce excellent pieces of art.

The purpose of an ideal model in architecture is not necessarily the actual production of a building. Many models serve merely the purpose of fulfilling the designer's imagination and satisfying his/her need to create a perfect world. On the other hand, models, such as mathematical, social, and statistical, are rational constructions, which are supposed to describe real-life phenomena. By altering the parameters that describe those models one is able to interpolate and extrapolate the data and understand their behavior. Moreover, alterations under extreme conditions reveal behavior far more unpredictable than a human mind can imagine.

In mathematics, notions such as randomness, reality, and imagination have been extensively investigated. The fact that in nature certain phenomena have a possibility of existence that cannot be predicted gives rise to the concept of *randomness.* A one-to-one correspondence of natural objects to discrete representations in our minds defines the world of *reality.* Finally, the absence of a fact or an evidence of reality gives rise to the concept of *imagination.* In imagination, we do not know the nature of the elements we are dealing with; we are only sure about the relationships that determine their behavior. Elements such as infinity, zero, and the square root of minus one are objects of imagination. Unlike random elements, the existence of imaginary elements cannot be explained, but their behavior can be described through rational relationships.

Parallel with the history of architecture is the history of media technology by which abstract entities such as events, experiences, and ideas become symbolically represented and transmitted through electronic devices. Through the use of mathematical models, it has become possible to visualize those abstract entities, verify their existence, and project their behavior into a once unimaginable world. The introduction of new electronic media in the last sixty years gave a different twist to the exploration of these mathematical notions. The ideas of mathematical models and simulations were realized through fast computations and large memory capacities. A world was *discovered*, the world of *simulations,* which is a "make-believe" representation of mathematical models. This world can be projected to the computer screen or animated through real-time computations. Objects, represented through instructions in the computer's memory, were projected to a screen by simple algorithms, then transformed as if they were physically there, occasionally dressed in fancy textures and, in special cases, animated and transformed indefinitely.

Since the invention of the digital computer, theorists strive to find ways to relate computers to human thinking. Computers are arithmetic devices, which can perform all basic arithmetic operations, such as addition, subtraction, multiplication, and so on. By combining basic operations computers are also able to perform complex algebraic operations and derive accurate results in minimum time. Furthermore and most importantly, computers have the ability to operate as logical devices, in the sense that they can perform logical operations, such as IF, THEN, ELSE, AND, OR, and so on. Given a number of truth tables, computers are able to verify the truth or falsity of a logical sentence or expression and therefore to determine the validity of an argument. This latter capability led computer theorists to inquire whether those arguments could be compatible to problems taken from the real world. In other words, whether it is possible to develop cognitive mechanisms, which would process information from the real world and derive answers or propose solutions, as if they were carried out by human beings. Some theorists expect to see even more than that. They expect to see computers, which would be able to simulate human thinking to a degree such that they would perform tasks, which are considered by humans to be highly intellectual, such as design.

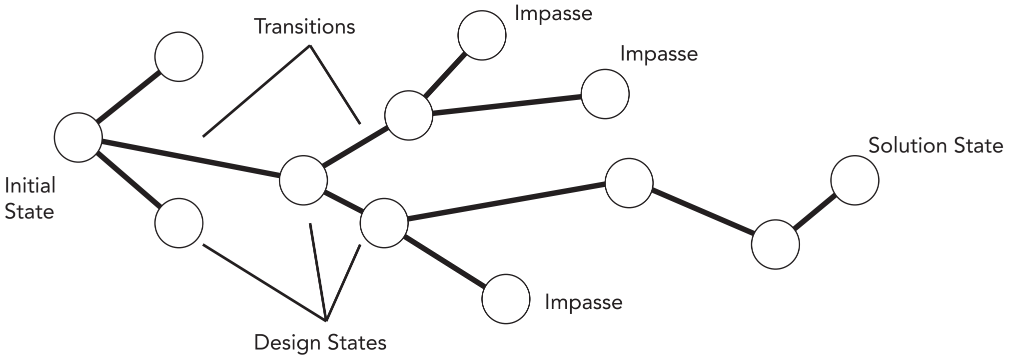
Design is a mental process that has puzzled people for many years. It is a process that everybody knows when one sees it happen but is hard to know how it is done exactly. The design process has divided people into two extreme positions on how it is performed. Many tend to feel that when one designs a product, or a house, or a poster, that the designer "follows his heart" and it is impossible to find out what is going on in the human mind during the design process. They also tend to go as far as to say that if a designer tries to reveal or describe the process of creation this will spoil the purity of the process and the designer will not be able to design that way again.

On the other extreme, there are people who think that design is a rational process regardless of whether the particular designer can express it in words or not. They believe that when a designer creates something, the designer follows a series of steps, rules, or tactics that are very logical. In that sense, diagrams, flowcharts, and algorithms can be created to depict and re-create the design process. Computers tend to be a great tool for these believers, because as rational machines they can be programmed to perform the same steps as those of the designers. The only thing that needs to be done is to find, codify, and feed the computer with those steps, rules, and tactics and then design will occur. This however has not happened yet. No computer can design as well as a human designer, or so the experts say.

At the same time, many designers admit that they reach limits during the design process. What they have in mind often cannot be drawn with their own traditional tools. As a consequence, the truth may lie in-between. Computers can be programmed to do things that designers can then use to enhance the design process. For example, computational design is one way of using computers during the design process as a medium to design better or different. It uses the computational and combinatorial power of a computer to generate schemes that can be useful to designers. It can also help designers synthesize forms, alter their shapes, and combine solids in ways often unpredictable. Computer graphics, on the other hand, is used as a way of depicting the end product so realistically that even the best artist cannot paint that fast and/or accurately. Computer graphics uses the computer screen as a means of projecting a complex world that either resembles the real world we live in or is completely based on imagination. One of the original main objectives of computer graphics was to simulate reality as close as possible. Light, color, motion, facial expression, anything that is associated with the real world can be codified and re-enacted in a computer-simulated world. At the same time, alteration of the real world led to imaginary conditions that are also important in computer graphics. Fractals, morphing, or grammars are methods that cannot be found per se in the real world, and as such are imaginary.

To identify the problem of design in general it is necessary first to define the term *design.* While many definitions and models of design exist, most agree that design is a process of inventing physical things which display new physical order, organization, form, in response to function. However, since no formula or predetermined steps exist which can translate form and function into a new, internally consistent physical entity, design has been held to be an art rather than a science. It is considered to be an iterative, “trial-and-error” process that relies heavily on knowledge, experience, and intuition. Intuition became a basis of many design theories, often referred to as “black box” theories. According to them, design, as well as its evaluation, tends to be highly subjective.

In contrast, another set of theories defines the design process as a rational *problem-solving process.* According to the latter, design can be conceived as a systematic, organized, rational activity. As defined by researchers over the past fifty years, for every problem there exists a solution space; that is, a domain that includes all the possible solutions to a problem. If design is seen as a problem-solving activity, the theory implies that there is a design solution that can be invented. Problem solving can be characterized as a process of searching through alternative solutions in this space to discover one or several which meet certain goals and may, therefore, be considered *solution states.* The way by which the design problem will be solved can be either deterministic or probabilistic but always possible.



0.1 Design stages during the design process

In the early 1960s, Alexander published a highly influential book titled *Notes on the Synthesis of Form*.[2] In it Alexander quotes the need for rationality in the design process. If design, he argues, is a conceptual interaction between form and context, there may be a way to improve it by making an abstract picture of the problem, which will retain only its abstract structural features. As a mathematician, he introduced set theory, structural analysis, and the theory of algorithms as tools for addressing the design problem. He asserted that even quality issues could be represented by binary variables. If a misfit occurs, the variable takes the value 1; if not, 0. Each binary variable stands for one possible kind of misfit between form and context. This approach was followed by a flurry of related research into the problem. However, Alexander's contribution was much more far-reaching. He introduced computers into the design process by suggesting which aspects of the design process are amenable to systematization and which are not. Further, he suggested that the design process entails frequent changes of mind (or changes of constraints, in scientific terms) and that a system should permit these changes to occur.

Traditionally, design is a mental process of arranging parts in a way that is most efficient, attractive, and/or meaningful. Even though design seems to be a mental function with an end product it differs significantly from discipline to discipline. In product design, emphasis is placed not only on the efficiency of the end product but also on the aesthetic value of it. In architectural design, function is an important factor in the design process but the form of the building is also very important. In engineering, often the design process can become very rational and design decisions can be made entirely on cost and efficiency.

The design of a product, for example, involves a concept formation, decision strategies, operations analysis, and research methods. *The concept formation* phase of any design project is probably one of the most difficult to define and manage. It includes brainstorming, morphological analysis, and prototyping. The *decision strategies* are used to assess and evaluate situations as a basis for making decisions. Some of the methods are designed for use by experts or a small group of experts. This phase includes decision analysis and value analysis. The *operations analysis* is used to model or study the behavior of a design, or a particular aspect of a design. It can be applied to an existing system, to study its behavior, or to one that is being developed, to model how it will behave in the future. It includes flow models, heuristic models, input-output models, interaction analysis, network analysis, optimization models, sequence analysis, simulation, and task analysis. The *research methods* are used to gather, investigate, assess, and verify information related to the needs of a design. They can be used to research the content needs of the design as well as the needs defining the context of that design. They include experimental models, focus groups, knowledge search, technology assessment, usability testing, and user surveys.

The introduction of computers capable of carrying out complex tasks led eventually to their inclusion in the "design process" debate. One of artificial intelligence's focuses is in the development of algorithms and methods that will codify the process of design. If and when that happens computers can design on their own by simply following these algorithms and methods. Even though a complete computer design system has not been yet developed that could compete with a traditional human designer, the theory of how to codify design methods led to a new way of looking at design methods. These ways range from complete optimism, where a computer can design on its own, to realistic approaches, where the computer functions as tools for the human designer. In the following sections we will describe briefly some of these attempts.

With the introduction of the first relatively complex computers, theorists investigated the possibility of self-designing machines. They thought that one of the areas where the computer could be helpful to a designer could be in automatic design; that is, in finding a large number of possible schemes at a sufficiently early stage of the design process, and choosing the best one for further development. An early attempt was systems, which could be used to describe spaces that might go into a building, indicating their dimensions, their arrangement, and their materials. The computer then arranged the spaces solving the problem. This approach has been used extensively ever after for solving complex design problems that are related to arranging parameters in optimum locations. These approaches focus on the functionality of the end design product and do not take into account aesthetic or artistic parameters. In areas such as design of computer chips, nuclear plants, or hospitals automatic spatial allocation plays a very important role today.

Some theorists have argued that many problems cannot be solved algorithmically, either because the procedure leading to their solution is ill defined or because not all the information needed to solve them is available or accurate. Such problems make it necessary to use *heuristic and adaptive decision procedures*. Heuristic methods typically rely on trial-and-error techniques to arrive at a solution. Such techniques are, by definition, much closer to the *search-and-evaluate* processes used in architectural design. In adaptive procedures, the computer itself learns by experience, which could follow a procedure, and, at the same time, could discern and assimilate conversational idiosyncrasies. Such a mechanism, after observing a user's behavior, could reinforce the dialogue by using a predictive model to respond in a manner consistent with personal behavior and idiosyncrasies. The dialogue would be so intimate such as that of a close and wise friend assisting in the design process.

In systems, known as *expert systems*, knowledge about a specific area of human expertise is codified as a set of rules. By means of dialogue with the user, the system arrives at a solution to a particular design problem. New knowledge is provided by the user to the knowledge base without a programmer having to rewrite or reconfigure the system. The ability of the system to justify conclusions and to explain reasoning leads to further systematization of the design process, but also, sometimes, to unpredictable behavior by the computer.

Historically, as a result of growing computer capabilities during the 1960s, automated design engendered a great number of expectations. Unfortunately, most of these expectations were not met, perhaps because machine intelligence was overestimated. Some types of design, such as architectural design, are much more complicated processes because they entail factors that cannot be codified or predicted. The heuristic processes that guide the search rely not only on information pertinent to the particular problem, but also on information which is indirectly related to it. In addition, the states that describe the design process do not exist before they are generated. Therefore, a solution state can only be identified "after the fact"; that is, after it has been generated.

These problems, as well as the computer needs of design offices, led to changes in the approach to automated design. Rather than emulating designers, the approach after the 1970s was predicated on the belief that they should be supported. The machine was introduced as an aid to instruction, as a mediator for the goals and aspirations of the designers. The computer could communicate with designers by accepting information, manipulating it, and providing useful output. In addition to synthesizing form, computers were also able to accept and process non-geometric information about form. These needs eventually led to the development of Computer-Aided Design (CAD).

Computer-Aided Design was developed to assist the designer during the design process. The assistance was in the form of drafting, modeling, rendering, and presentation. The first CAD systems date as early as the 1960s, with systems that could allow the user to draw, draft, and visualize some basic 3D models. Most of these systems were used in the automotive and aerospace engineering mainly because at that time they were the only ones that could afford such systems. With the popularization of the microcomputer and a significant fall in the prices, architects and graphics designers started to use CAD systems. One of the interesting debates in the 1970s was whether CAD was useful or not for these designers. This debate kept going on in the 1980s and today we can see that a majority of architectural and graphics design offices use computers in almost all phases of the design process. In most engineering areas, CAD became a valuable tool for design, evaluation, estimation, and optimization. CAD systems and interactive graphics are used to design components and systems of mechanical, electrical, electromechanical, and electronic devices, including structures such as buildings, automobile bodies, airplane and ship hulls, very large-scale-integrated (VLSI) chips, optical systems, and telephone and computer networks. Further, large and efficient database management led to the integration of data and geometry in the form of Building Information Management (BIM). Many CAD systems consequently transformed from geometrical systems to data-rich BIM systems where information is not only stored but also updated through Internet communication protocols.

As design began to be increasingly thought of as a systematic and rational activity, many of its empirical and experimental rules were explored. By operating on symbolic structures stored in the computer's memory and manipulating them according to rules, computers could reason about, or even predict, the behavior of a simulated environment. The machines were made to carry out a "make-believe" happening, a *simulation*. The purpose of a simulation is to use or operate on a model (often a mathematical model encoded in a computer program) to learn about the behavior of the reality being modeled. Numerous simulation models were formulated and much progress was made toward simulating design states. These models simulated the states of a designed environment and the transitions from one state to another. Yet, no model was formulated which could encompass both the relationships between the components of a design and its environment.

Computer graphics is related to design and simulation by being a method for display and visualization of design products or processes. Research in computer graphics can be divided into two general directions: representation of the known and representation of the unknown. In the first category, reality is the competition. In other words, research in this area focuses in finding ways of perfectly representing objects, scenes, or behaviors that can be found in the real world. Image processing and object representation fall into this area. In the second direction, focus is placed on representing objects and behaviors that are not known in advance. Simulation and procedural graphics fall into this category.

Representation of the known is based on techniques for representing the real world. The real world that surrounds us can be seen either as a projection of the retina of the eye or as existing in three dimensions as material forms. In the first case, computer graphics uses the surface of the computer screen as a medium for projection. Color samples from the real world are associated with tiny dots on the computer screen called pixels. By manipulating color intensities, hue, and saturation projected scenes can be displayed. Furthermore, by altering the values of the pixels one can analyze, synthesize, transform, and juxtapose the picture. In the second case, three-dimensional objects in the real world are abstracted as geometric forms and are codified in the computer's memory. This process is called *modeling*. As a result of modeling, objects are represented as geometric shapes, and then as numbers. Furthermore, models are rendered with textures, shades, and shadows to resemble their original objects as accurately as possible. The export of such data into the real world using sculpting or layering devices allows the creation of 3D physical objects through a process referred to as *fabrication*. In all these cases, the objective of representation is known: to depict as accurately as possible the real world.

Representation of the unknown is based on alterations of techniques used in the representation of the known. By observing structures and processes that hold together the real world, one can alter or extrapolate them obtaining unknown or unpredictable results. Simulation is the process of using or operating a model (often a mathematical model encoded in a computer program) to learn about the behavior of the reality being modeled. But simulations can be performed to learn about the unpredictable behavior of a reality being modeled, such as molecular or weather phenomena. Similarly, simulations can be performed to visualize imaginary scenarios, such as art and movies. These simulations allow us to see beyond reality and to experiment with imaginary structures and processes.

Computationalism is a term coined here to denote the theory that, through the use of computation, knowledge can be acquired that is impossible or foreign to the human mind. There are two terms that need to be defined here first: impossible and foreign. Impossible refers to the inability to predict a result due to a large number of calculations. Foreign refers to the inability to comprehend the results of such calculations. For example, the solution or visualization of a recursive equation (e.g. a quadratic polynomial) may reveal behaviors unpredictable and often unexplainable, yet true. The assertion of truth is based on the rational structure of computational schemes and their consequent characteristic of being coherent, traceable, and consistent. Computationalism assumes that intelligence, as a rational process of problem solving, is not an exclusive privilege of the human mind but rather can be abstracted as a generalized process, codified in the form of rules, and then re-implemented into another medium, i.e. binary, chemical, biological, etc. In other words, human intelligence is a biological instantiation of a more general structure that manifests itself in what we define as intelligence. Further, the implementation into an alternative medium takes advantage of the properties of that medium rendering results much faster, accurate, or complex. Most importantly, a human is able to compare one's own process with that of another's non-human as to detect similarities or differences in performance, but also to engage in mutual or parallel synergy as to share, complement, and enhance either process.

The process of confronting design as a structured problem has been discussed by many theorists in the area of artificial intelligence (AI) and many models have been developed and implemented. The main concern of those theorists is the degree to which design can be rationalized. One position is that design is an ill-structured problem, but it can be solved by considering not one, but a spectrum of alternative solutions and choosing the most satisfying one. In order to produce these alternative solutions, design has to be first viewed as a problem-solving process.

If the design process is viewed as *a problem-solving process*, design may be conceived as a far more systematic and rigorous activity. In that sense, for every problem a *solution space* exists. That is, a domain exists that includes all the possible solutions to the problem. Problem solving can then be characterized as the process of identifying and evaluating alternative solutions in this space in order to discover one or several which will meet certain goals and may be considered to be appropriate and desirable. Four such cases will be offered as food for thought below: game playing, problem solving, perception, and language.

In game playing, one of the objectives is to make intelligent moves. For example, in chess, there are rules, strategies, and tactics. Every move has to fulfill local and global goals. In design, we can also acknowledge the involvement of rules, strategies, and tactics during the design process. The question, however, is what are the goals in design? What is the local and what is the global goal? One of game playing's properties is that although people who do them well are considered to be intelligent, it appears that computers can perform well by simply exploring a large number of solution paths in a short time and then selecting the best. It seems that this process required little knowledge and could therefore be easily programmed. In other words, the computer's involvement in the design process does not have to be that of imitation rather than that of extension.