Chapter 1: The Domain

Design, Graphics, and Science

Design is a mental process that has puzzled people for many years. It is a process that everybody knows when they see it happen but nobody know how it is done exactly. The design process has divided people into two extreme positions in 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 in the 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 that this will spoil the purity of the process and that the designer will not be able to design that way again.

On the other side of the spectrum, there are people that 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 that 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 that 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 design will occur. This however has not happened yet. No computer can design as good as a human designer.

At the same time on the opposite side, 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 lies in-between. Computers can be programmed to do simple things that designers can use to enhance the design process.

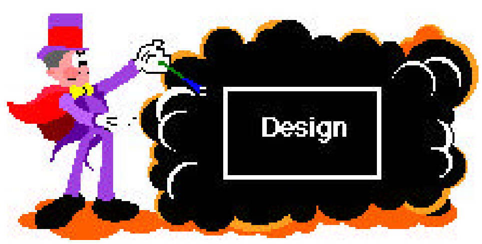
Computer-aided design is one way of using computers during the design process as an aid to design better or different. It uses the computational and combinatorial power of a computer to generate schemes that can be useful to designers. It can also help designers synthesize forms, alter their shapes, 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. Computer graphics use 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 main objectives of computer graphics is to simulate reality as much as possible. Light, environments, movements, facial expressions, anything that is associated with the real world is being codified and reenacted 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 in the real world, and as such are imaginary.

In the next sections we will investigate how and how much computers can be integrated in the design process and how do they rank compared to traditional design tools and processes.

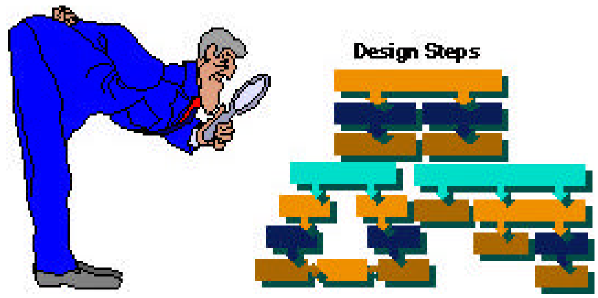
Design as Art and Science

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" [Alexander, 1964: 6]. 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, tend to be highly subjective.



The design process tends to be undefined and obscure

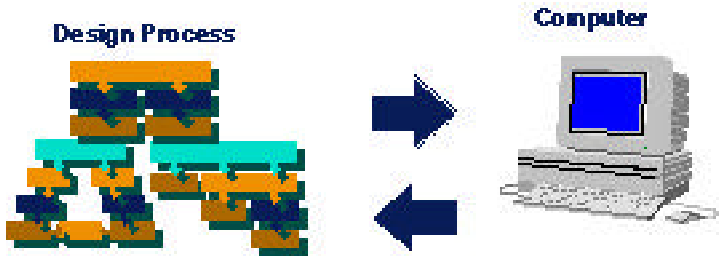
In contrast, another set of theories defines the design process as a rational *problem-solving process*. According to the latter, design can be conceived as a systematic, organized, rational activity. As defined by researchers like Alexander [1964], Newell and Simon [1972] over the past thirty years, 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.



Design can be seen as an organized, rational series of steps, rules, and tactics.

The Evolution of the Design Process

In the early 1960s, Alexander [1964] published a highly influential book titled *Notes on the Synthesis of Form*. 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 entail frequent changes of mind (or changes of constraints, in scientific terms) and that a system should permit these changes to occur.



If design can be computerized, then computers can design.

In the next few sections we will try to identify, describe, and evaluate the role of computers in design. Traditional design methods are discussed first, with particular emphasis on rational design steps. New design methods are discussed next and the contribution of computers to the design process. Third, the concept of digital design is discussed briefly.

Traditional Design Methods

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 efficiently 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. For the purpose of this book we will concentrate on design as a rational process and describe briefly some design methods.

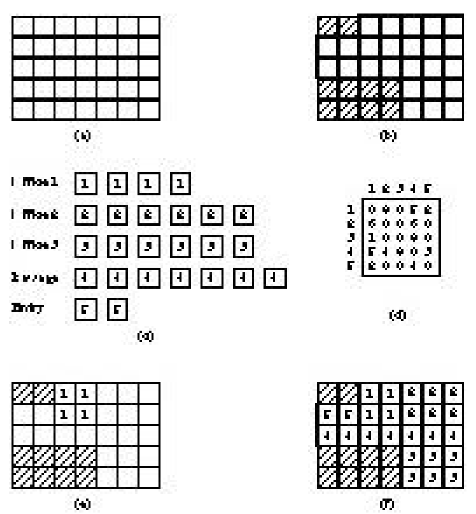
The design of a product involves a concept formation, decision strategies, operations analysis, and research methods. *The concept formation* phase of any design project is probably one of the most difficult to define and manage. It includes brainstorming, morphological analysis, and prototyping. The *decision strategies* are used to assess and evaluate situations as a basis for making decisions. Some of the methods are design 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. It includes experimental models, focus groups, knowledge search, technology assessment, usability testing, and user surveys.

New Design Methods

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 computer functions as tools for the human designer. In the following sections we will describe briefly some of these attempts.

Automated Design

In the 1970s with the introduction of the first relatively complex computers, theorists investigated into 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 MIT's BUILD system [Dietz, 1974] 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 design of computer chips, nuclear plants, or hospitals automatic spatial allocation plays a very important role today.



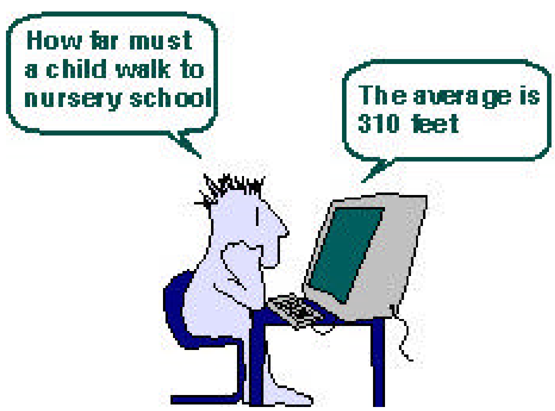
Space allocation process: (a) grid (b) site (c) program (d) relationship table (f) solution

Machine Learning

Some theorists have argued that many problems cannot be solved algorithmically [Gill, 1978], 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, as in Negroponte's "architecture machine" [1970], which could follow a procedure and, at the same time, could "discern and assimilate" conversational idiosyncrasies. This machine, 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, "that only mutual persuasion and compromise would bring about ideas." [Negroponte, 1970: 13] The role of the machine would be that of a close and wise friend assisting in the design process. This approach has been extensively used by many researchers [Kalay, Flemming].

Expert Systems

This approach became the basis of relatively recent developments. 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.

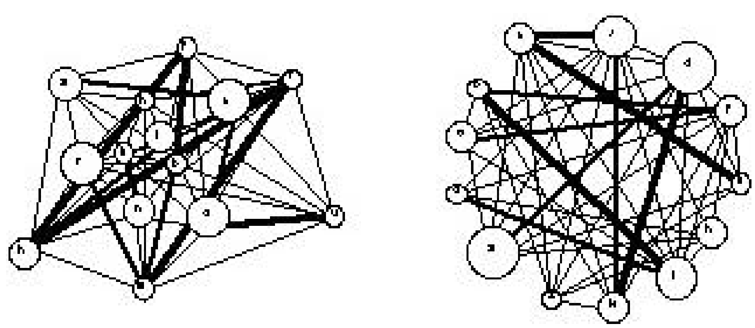


A expert system answers intelligently and predicts the user’s questions

Digital Design

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 in 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 could also able to accept and process non-geometric information about form. These needs eventually led to the development of Computer Aided Design (CAD).



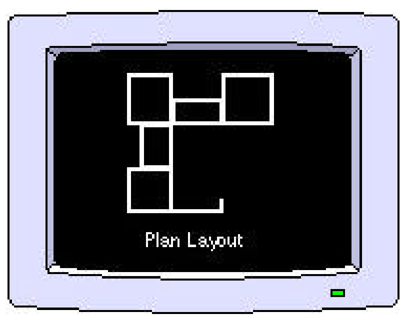
Design can become too complicated!

Computer-Aided Design (CAD)

Computer-aided Design is an area of computer graphics that 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 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 is 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.

Visualization

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 [Rasdorf and Kutay 1982; Lafue 1979]. 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.

Production and Office Automation

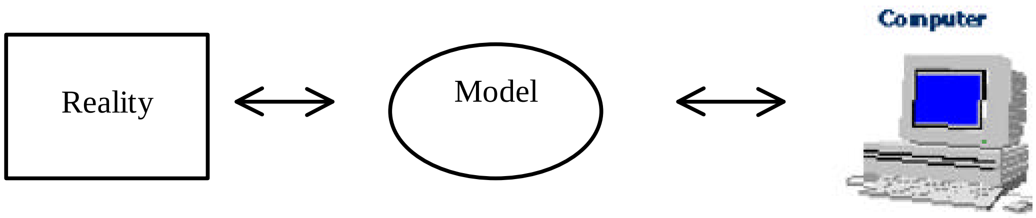
The use of computer graphics is not limited to CAD or visualization. Numerous tasks related to design are not necessarily form-creation related. The use of graphics for the creation and dissemination of information has increased enormously since the advent of the desktop computer. Many organizations whose publications used to be printed by outside services can now produce their publications in-house. Office automation and electronic publishing can produce hard copies and electronic documents that contain text, graphs, tables, images, and other scanned-in graphics. All this information can be published and shared on computer networks in the form of hypermedia documents.

Design production

Fundamentals of Computer Graphics

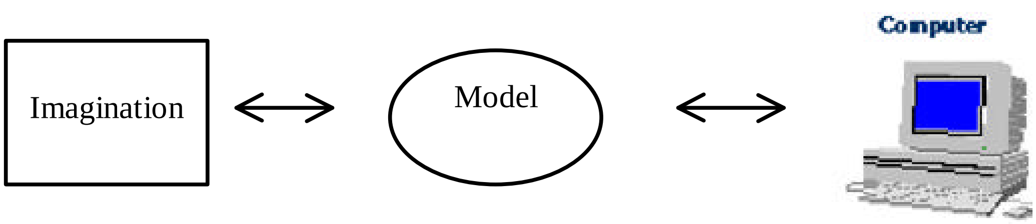
Computer graphics is the art and science of incorporating computer technology in the process of image creation and display [Kerlow and Rosebush, 1994]. Computer graphics is related to design by being a method for display and visualization of design products or processes. Research in computer graphics 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 focus in finding ways of representing objects, scenes, or behaviors that can be found in the real world. Image processing and object representation falls into this area, which will be described briefly in the next paragraph. In the second direction, focus is placed in representing objects and behaviors that are not known in advanced. Simulation and procedural graphics fall under this category, which will be described in the next paragraphs.

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 use the surface of 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 as 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 accurate as possible. In all these cases, the objective of representation is known: to depict as accurately as possible the real world.



Reality can be abstracted and encoded into a computer

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.



Imagination can be encoded into a computer

Brief History of Computer Graphics

The history of computer graphics is related to a large extent to the developments of computer technology. Many advancements in computer graphics over time can be associated with technological leaps that allowed these advancements to happen.

Computer graphics technology was developed in the early 1950s. At that time the first cathode ray tube (CRT) called *whirlwind* was used at the Massachusetts Institute of Technology (MIT). Some screen interaction was available mainly in the form of icons and light pens. During the 1960s the first Computer-Aided Design And Manufacturing (CADAM) systems were developed on mainframe computers to carry out engineering analysis and numerical computations. General Motors was one of the first companies to use one of these systems followed by Boeing, IBM, Lockheed and others. These systems could display and manipulate mainly two-dimensional shapes on the screen. In the mid-1960s three-dimensional representations were developed and later hidden line removal was implemented.

In the 1970s three dimensional animation and imaging is starting to appear. The development of the microcomputer led to an increasing popularization and commercialization of computer graphics. A typical 1970s microcomputer configuration would be an 8-bit microprocessor with 100 KB of RAM running at 10 MHz, with 256 color low-resolution monitor and limited peripherals. During this decade at the University of Utah under the guidance of David Evans new techniques for rendering three-dimensional objects were developed such Gouraud and Phong shading, bump texture mapping, and facial animation.

In the 1980s microcomputers became more powerful allowing researchers to develop more complex realistic effects. Spline modeling, radiosity, inverse kinematics, character animation, and lip syncing were some of the techniques developed during this period. Special effects companies for the movie theater appeared and some films with computer graphics scenes were developed such as TRON or the Last Starfighter. A typical 1980s microcomputer configuration would include a 32-bit or 64-bit microprocessor with a co-processor with a few Megabytes of RAM, running on more than 50 MHz, with a high resolution monitors and extensive peripherals. Video input/output became also available.

In the 1990s microcomputers became more powerful and less expensive. Systems were sold in a modular form while micro-supercomputers or workstations became available to consumers. A late 1990s computer configuration includes a 64-bit CISC or RISC microprocessor, with 128 MB of RAM, running at 300 MHz, with a graphics accelerator card, a high-resolution 17" monitor and extensive peripherals. Research and development was mostly centered on efficiency, cost, and ease of use. Friendlier computer-human interfaces made it easy for users to integrate and use their computers more efficiently in their work. The high-end computers available in the consumer market gave a boost to the electronic game industry. In the movie industry new techniques led to increased computer graphics involvement. *Terminator II* (1991) by Industrial Light and Magic (ILM) shows morphing effects and natural human motion. *Lawnmower Man* (1992) addresses issues of virtual reality and computer animation. *Batman Returns* (1992) has effects of flock animation. *Jurassic Park* (1993) demonstrates great examples of inverse kinetics.

In the last half of the 1990s vast computer networks led to the creation of the Internet and high computer speeds led to the possibility of real-time animation. These two factors became a guiding force in the development of a multi-user Virtual Reality Modeling Language (VRML). This allows a user to navigate in real-time in texture mapped worlds over the Internet and meet other users, called *avatars*, connected to the same world. Many of these advancements will continue into the next decade.

SUMMARY

- **Design** is a mental process that has puzzled people for many years. Many tend to feel that it is impossible to find out what is going in the mind during the design process. On the other side of the spectrum, there are people that think that design is a rational process regardless of whether the particular designer can express it in words or not.
- **Computer-aided design (CAD)** is one way of using computers during the design process as an aid to design better or different.
- **Computer graphics** is used as a way of depicting the end product.
- In the early 1960s, **Alexander** quotes the need for rationality in the design process. He introduced computers into the design process.
- Even though design seems to be a mental function with an end product it **differs** significantly from discipline to discipline.
- **Automated design** is the development of design by a computer without human intervention.
- Some think that the role of the machine would be that of a close and wise friend **assisting** in the design process.
- The ability of a computer system to justify conclusions and to explain reasoning led to **expert systems.**
- **Computer-aided Design** is an area of computer graphics that was developed to assist the designer during the design process.
- 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.
- The **use of graphics** for the creation and dissemination of information has **increased** enormously since the advent of the desktop computer.
- **Computer graphics** is the art and science of incorporating computer technology in the process of image creation and display
- **Representation of the known** is based on techniques for representing the real world. **Representation of the unknown** is based on alterations of techniques used in the representation of the known.
- Computer graphics **technology** was developed in the early **1950s**.
- In the 1970s **three dimensional animation and imaging** is starting to appear.
- In the 1980s **microcomputers** became more powerful allowing researchers to develop more complex realistic effects.
- In the 1990s microcomputers became **more** powerful and **less** expensive.
- In the last half of the 1990s vast computer networks led to the creation of the **Internet** and high computer speeds led to the possibility of **real-time** animation.

KEY WORDS

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EXERCISES

1. Write a short paper (1-2 pages) on the following topics:

- What is **Real** and what is **Non-Real?**
- How can the computer **help me** communicate an idea?
- How can the computer help you explore something **you do not know in advance**?

2. Read the paper entitled "**The Role of Computers in Architectural Design**" (following page) Answer the following questions:

- Why is Alexander's contribution **important** to CAD?
- Can computers **improve** architectural design (not drafting)? Why or why not? How?
- List one difference between **architectural** design and **engineering** design?

3. Is geometry a human **invention** or a human **discovery**? Why?
   (Hint: there is no right answer. You will be graded on the degree of argumentation)

THE ROLE OF COMPUTERS
IN ARCHITECTURAL DESIGN

To identify the problem of design in general, and of architectural design in particular, it is necessary first to define the term *design*. While many definitions 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, 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 is a basis of many design theories, often referred to as "black box" theories. According to them, design, as well as its evaluation, tend to be highly subjective. In contrast, another set of theories defines the design process as a *problem-solving process*. According to the latter, design can be conceived as a systematic, boundedly, rational activity.

In the early 1960s, Alexander published a highly influential book titled *Notes on the Synthesis of Form* . 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. This approach was very important. It introduced computers into the design process by suggesting which aspects of the design process are amenable to systematization and which are not.

One of the areas where the computer can be helpful to an architect is in space allocation, 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. However, because of the large number of constraints to be simultaneously considered in an architectural design problem, it would be difficult to meet them all. Moreover, the complexity of the design problem is so great that a designer would be unable to arrive at an appropriate solution.

These problems, as well as the computer needs of architectural offices, led to Computer Aided Design (CAD). Rather than competing with architects, the approach was simply to help them. The machine was introduced as an aid to instruction, as a mediator for the goals of the architects. The computer could communicate with architects by accepting information, manipulating it, and providing useful output. In addition to synthesizing form, computers are also able to accept and process non-geometric information about form. Therefore, it was necessary for architectural design languages to be invented to describe operations on building databases.

However, computer-aided design failed to improve the architectural design process and products. Over 90 percent of the systems that have been installed worldwide are used only for drafting or site planning, which are not, in themselves, essential steps in the process of architectural design.

The failure of CAD to improve the architectural design process and products is probably due to the fact that most of the researchers did not consider the idiosyncrasies of architectural design. In architecture, design quality is reflected in forms and their relationships. Many architects and theorists have argued that what distinguishes a well-designed building from one that is poorly designed can only be found in the morphological relations that the former embodies. "One can have a beautiful idea of winning a chess game. One can brutally win a chess game in a very inelegant way. But there can be an elegance in the process of winning itself, that is poetic."

QUIZZES

1. **CADAM** stands for:
   a) Computer-aided design and manufacturing
   b) Computer-aided drafting and modeling
   c) Computer-aided development and manufacturing
   d) Computer-augmented design and modeling

Circle 1: a b c d

2. When did the **first** computer graphics systems started to appear?
a) 1940s
b) 1950s
c) 1960s
d) 1970s

Circle 1: a b c d

3. Computer Graphics is and **area** of Computer-aided Design.
a) True
b) False

Circle 1: a b

4. According to "**black box**" theories, design, as well as its evaluation, tend to be highly subjective.
a) True
b) False

Circle 1: a b

5. What **characterizes** the late 1990s?

a) three dimensional animation
b) imaging
c) special effects
d) vast computer networks

Circle 1: a b c d

ANSWERS

1. a) CADAM stands for Computer-Aided Design And Manufacturing
2. b) 1950s
3. b) False. Computer-aided Design is an area of computer graphics.
4. a) True.
5. d) vast computer networks