COMPUTER APPLICATIONS IN ARCHITECTURE: FORM GENERATION TOOLS

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ABSTRACT

In the age of globalization (and fierce competition), architects in developing countries have to keep pace with the latest advancements of technology and computing. The majority of architects may not be fully aware of the applications of computers in architecture except for the applications of computer aided drafting, modeling and visualization. This has resulted in that computing has not penetrated all the architectural tasks evenly. The problem in developing countries is even greater.

However, whether in developed or under developed countries, one of the least explored areas is the area of computer aided form generation. This is evident in the rareness of software that aid architects in this area. This study is out to investigate the latest applications of computers in architectural design form generation.

The study proceeds to review background and historical information. The two branches of form generation tools were identified, namely, generative tools (the fist branch) and concept development and sketching tools (the second branch). Exemplary applications of computing in design synthesis in architecture were investigated. The current status was analyzed and the latest developments were emphasized for both branches.

The study closes with the conclusions and directions for further research. Among the findings of this study were that the second branch is developing in a much faster rate than the first branch. The second branch is developing rapidly in the directions of the ease of use and internet collaboration. The main problem with the first branch seems to be inherited from the larger realm of the science of artificial intelligence.

KEYWORDS: architectural design, computers, form generation, synthesis, information technology, design process, future, state of the art, practice, Egypt

1. INTRODUCTION

Synthesis is the creation or generation of formal design solutions. The process of synthesis is thus one of hypothesizing the form that the solution, or some part of the solution, might take. Everyday new applications are becoming available for architects to use but many architects simply do not know anything about them. Computer tools that aid in form generation are no exception. In addition, the task of form generation seems to be the least computerized task of the design process.

For all the above, a study about state of the art applications of computers in architectural form generation is needed.

Several fragmented studies have been done to gather the state of the art applications of computers in the architectural form generation. One of the latest attempts to do so was by Phiri[1] in 1999, which is out dated. There is a general lack of references that collect the state of the art in the applications of computers in architectural form generation during the last five years. This has coined the goal of this study.

Thus, the goal of this research is to explore and analyze the use of computers in architectural form synthesis and to point out the state of the art in this field. The practical use of each technology is emphasized.

The scope of this study can be defined as follows:

- Where possible this research will be limited to the past five years as it is impractical to investigate deeper in history.
- The relationship of computing and architecture has at least three faces: practice, education and research. Although we shall touch all these faces, more emphasis will be given to the first face. This gives this research a practical orientation.

The logical structure of this study goes as follows:

- This study starts with an introduction where the literature review, goals, scope, methodology, and structure are stated.
- The roots of computer aided architectural form generation are then traced
- Then, the study proceeds to review background information about the design process and form generation.
- That being said, computers and information technology applications for form generation shall be investigated, the current status is described and the latest developments and their practical uses are emphasized.
- The study closes with the conclusions and directions for further research.

The method used through out this study is a theoretical and analytical method. After the theoretical and historical backgrounds of the topic are laid out, state of the art applications are investigated with a general orientation towards the architectural practice.

2. THE ROOTS OF COMPUTER AIDED ARCHITECTURAL FORM GENERATION

Although the earliest installations of general purpose computers date from the early 1950's, the roots of computer aided architectural design (CAAD) extend to the early 1960's.
The early roots of CAAD development is marked by four early events that influenced the use of computers in architectural design form generation[2] .

A- The first event was a set of studies that formed the foundation of computer aided layout planning and form generation. The first of these were the studies on planning of hospitals carried out by Souder and Clark and published in 1963[3] and 1964[4]. Parallel to this work came other studies carried out by Archer[5] in 1963, Armour and Buffa[6] in 1963, Moseley[7] in 1963 and Whitehead and Eldars[8] in 1964. All these studies were in the direction of (Figure 1) optimizing the plan layout to minimize the cost of movement of the tenants between spaces. This formed the foundation of generative design tools.

B- The second event dealt with the graphical representation and manipulation of buildings as objects. Sutherland's[9] "Sketchpad"[10] system[11] in 1963 pioneered this field (Figure 2), and it was followed with work of Newman[12] in 1966, the 1964 Boston Architectural Center conference, the 1969 Yale conference specifically on computer graphics in architecture and the work of Campion[13] in 1965. This formed the foundation of concept-development and sketching tools.

C- The third event was the start of laying the foundations for design methods: the view that design can be externalized and described. This view was fundamental to the use of computers in architectural design and was a direct or indirect effect of the publication of Christopher Alexander's[14] "Notes on Synthesis of Form" in 1964.

D- The idea of the "Architecture Machine" emerged in 1972 as a part of the wave of optimism about artificial intelligence and robotics. The concept of the "Architecture Machine" was pioneered by Negroponte[15] in his book "The Architecture Machine." This machine is supposed to be intelligent enough to carrying out the design while cooperating in a dialog with the architect.

3. FORM GENERATION AND THE DESIGN PROCESS

Gero[16] in 1973 defined the design process to mean "the process by which solutions to constrained problems are arrived at." By constrained, Gero meant that the constraints on the problem are all known even if they may not all be objectively described.

This process is traditionally broken[17] down into several phases[18] e.g. 1) program development, 2) schematic design, 3) preliminary design, 4) design development, 5) contract documents, 6) shop drawings, and 7) construction, in addition to post occupancy management and maintenance.

For design to progress from one phase to the other successfully, a problem solving technique should be applied. There are many problem-solving models (techniques) that are applicable to the design process. (See for example studies by Gero[16] in 1973, Steadman[19] in 1987, Schmitt[17] in 1988, Maver[20] in 1985 and Broadbent[21] in 1988). The traditional design problem-solving model (Figure 3) --upon which there is some agreement[20] -- is the following five-step procedure[21] **A. Analysis (Problem and Design Objectives Definition):**

Analysis is the process of collecting, collating and correlating the information relevant to the design problem. The limits of the problem are identified. The problem is decomposed into smaller problems and analyzed.

Constraints and resources are evaluated and design objectives established.

B. Synthesis (Form Generation):

This is the task of the development of alternatives and the process of hypothesizing viable formal solution(s) (that is, generating forms) to the design problem.

C. Appraisal (Evaluation):

Appraisal is the process of testing and evaluating the solution(s) against cost and performance criteria according to the design objectives.

D. Selection:

Based on the appraisal, a solution is selected. If there is no overall best alternative, successful parts of several alternatives may be combined and appraised.

E. Presentation:

The final solution to the problem must be presented in an appropriate way whether to the client or for the next step of design.

These five steps may operate cyclically at various levels of detail as the design idea take shape and through out the design phases. These five steps are not performed rigidly, in real life, creative design may break some rules, objectives may be redefined and new weighting factors may be assigned.

Thus, form generation (synthesis) is in the heart of the tasks of the design process. The problem solving model above is useful in defining the scope of various architectural design tasks and is a valid method for classifying the total spectrum of computerized design tools.

After the general tasks of architectural design were investigated, we shall be exploring in the next section the applications of computers for the task of synthesis.

4. TYPES OF FORM GENERATION (SYNTHESIS) DESIGN-TOOLS

Synthesis design-tools may be broadly classified into “generative design-tools” and “concept development and sketching” tools. The following sections will look at both and will trace the latest developments in both.

4.1. Generative Design-Tools

Generative design-tools produce designs from basic input data. Practical generative methods are very difficult to develop, as it is not possible to build into a computer program many of the most important factors essential for good design[11]. However, generative expert systems

and shape grammars may be promising in the future (see for example studies by Coyn[22] in 1988 and the Shadyside experiment of Carnegie Mellon University).
It is relatively easy for the designer to design a window and then leave to the computer, using analytical design tools, the task of assessing the energy gain and the level of natural lighting in the room. The alternative, using generative design tools would be to make the computer produce a window that meets certain natural lighting level and certain heat gain. This may produce thousands of solution. The designer is forced to choose out of all the solutions an appropriate one.

4.2. Concept Development and Sketching Tools

Although freehand-like sketching has long been possible with pixel-based "raster paint" software like Photoshop, and with Macintosh CAD software like PowerCADD, conventional CAD applications like AutoCAD and MicroStation have not provided a way to bring in those sketches for further development. Instead, the transition from sketch to CAD has usually meant abandoning the freehand sketch at some point while starting over in a digital medium.
In an effort to bridge that transition, and to make entry into a digital environment more accessible to those who prefer pencil sketching, concept-development and sketching tools like DesignWorkshop and Architectural Studio, allow the architect to sketch in 2D and 3D. Such tools try to replace pencil and paper, therefore, they emphasize on the ease of use rather than on the accuracy of the model. They often have basic rendering abilities. Figure 4 shows an example of the output of such tools.

5. LATEST TRENDS IN GENERATIVE DESIGN TOOLS

Following, this study will explore the latest trends in generative design tools; practical-use and applicability are important criteria in the selection

5.1. Generative Design Tools That Use the Laws of Physics to Generate Designs

One example of modern attempts of creating a generative design-aid is from the Department of Architecture at Texas A&M University in College Station. Scott Arvin, working with Professor Donald House, has developed a system[23] (Figure 5) for "physically based space planning." Arvin's computer prototype accepts building program parameters (square footages, adjacency and separation requirements) and constructs viable floor plans.
This system is the digital equivalent of moving around scaled pieces of paper to create a plan configuration except that the individual pieces can change shape, multiple complex considerations can be simulated simultaneously and automatically, and the resulting footprint has exterior walls aligned flush, to create a simple footprint.
Each space in a bubble diagram is attached to other spaces by springs. The architect assigns a relative strength to each spring proportional to the need for adjacency between the two spaces. Arvin's computer program applies the laws of physics to the springs to pull some spaces together and push others apart, until the configuration reaches equilibrium. For example, a kitchen and dining room would be pulled together while a concert hall and a noisy loading dock would be pushed apart.
Similar physical simulations are performed for moving spaces that require particular views to particular orientations, for moving interior spaces toward the center of the overall footprint, for aligning the boundaries of adjacent spaces, and for maintaining the necessary area or proportion of each space. All of this occurs in an animated format, allowing the designer to observe the effects of the specified parameters.
The designer interacts with the various parameters and makes continuous adjustments. This adds the designer's intelligence to the simulation and affords multiple workable plan configurations from which to choose.

5.2. The Rise of Specialized Generative Design Tools

New generative design-tools are appearing to help architects to generate form for specific problems like parking lots (Figure 6). VectorWorks Landmark software incorporates profession-specific tools for landscape architects such as a parking lot layout tool[24], which helps the designer create the geometry for a variety of parking configurations .

5.3. Wizard Based Generative Design Tools

Wizard based generative design-tools are appearing to form a dialog in which the architect and the computer take turns in defining and solving the design problem. A new generative design-aid is the **"House Wizard"** of Chief Architect software, from ART, Inc.. One of Chief Architect's (Figure 7) newest features is the "House Wizard," a space-diagramming tool capable of doing preliminary massing for houses[25]. Through a series of dialog boxes, the user specifies all the room types desired in a new design. Chief Architect then creates rectangular shapes to represent the rooms in plan.

The shapes' initial sizes are arbitrary, but as the user stretches their sides to adjust size and shape, the software reports back on the size of the room being created. When the shapes are properly sized, the user arranges them in a spatially logical way. Multiple floors can be developed similarly, with Chief's "ghosting" function used to reference and align walls between floors.

Then the software takes over to create interior doors between spaces and exterior walls to enclose the whole. The user specifies roof type and overhang, and the software automatically creates a workable roof form.

Although this form-generation is preliminary, it provides a fast and effective way for creating several massing alternatives to show clients and to study possible space arrangements and roof forms.

5.4. Generative Design-Tools That Help inSynthesiz ing New Types of Structure Systems

New generative design-tools create new types of structure systems. One example is a parametric model developed by Katharine Liapi at the University of Texas that allows architects to visualize and design with tensegrity structures (Figure 8). Tensegrity structures are complex forms in which the compressive members do not touch each other[26] . These are seldom found in real applications. Professor Liapi's computer model enabled her to generate a tensegrity structure in the overall shape of a sphere and supported on four supports.

6. LATEST TRENDS IN CONCEPT DEVELOPMENT AND SKETCHING TOOLS

Following, this study will explore the latest trends in concept development and sketching tools. Among the main criteria for identifying these trends were practicality and applicability in architectural practice.

6.1. Mimicking the Traditional Architectural Desk in a Sketching Environment

Among the latest trends in concept-development and sketching tools is the trend towards mimicking the traditional desk of an architect and his common tools. One example of such trend is the recently released Autodesk Architectural Studio software. This software provides an interface styled to resemble an architect's traditional desk and includes tools to support 2D sketching, mechanisms to merge sketches into 3D models, and a collaboration environment for working on projects with others at remote locations.

Tools are kept deliberately simple. They include pencils, markers, erasers, and tracing paper. The screen, like a conventional desk, can be filled with imagery from many sources: scanned photographs and hand-drawn sketches, drawings imported from other projects, stacks of alternative concept sketches, renderings, and GIF animations. With the tracing-paper tool, architects can overlay translucent "trace" and develop new variations of a design while

preserving old ones. Sketches made within this environment look much like sketches that have been hand-drawn, scanned, and imported (Figure 9).
What makes this different from conventional "paint" software is that the on-screen sketch strokes are mathematically-based objects, subject to resolution-independent scaling and computation, and they can be used as a base in Architectural Studio's 3D modeling mode. Thus, users can extrude massing models from a base sketch without knowing much about the technicalities of 3D computer modeling.
Similarly, and as in the conceptual modeling software DesignWorkshop, traditional, pencil-drawn sketches can be scanned and brought into Architectural Studio, and used as a template for modeling[27]. Once a 3D model is built in Architectural Studio, it can still be subjected to sketch development, using 3D as well as 2D tracing paper (whereas only 2D sketching is supported in current versions of DesignWorkshop). This allows the architect to continue working with simple paint-like sketching tools, but with easy access to the visual feedback afforded by a scaled 3D model. And, without having to start from scratch, the user can export the models resulting from such schematic design processes to more technically complex software for further development and rendering.

6.2. Collaboration From Within Sketching Software

Another new trend allows the architect to collaborate with the rest of his team (who may be far away) from within a common 2D/3D sketching environment. Software like Autodesk Architectural Studio maintains a centralized data center where users publish their work to a private Web site[27]. Two or more people in different locations can work together as if they were sitting and drawing simultaneously at the same drawing board. With the addition of a simple videoconferencing setup — a camera and microphone on both ends — groups can also see and hear each other and conduct a design review (Figure 10) as if they were in the same room.

6.3. Sketching Hardware That Facilitate Hand/Eye Coordination to Produce a Natural Interface with the Architect

Interactive “pen displays” form a powerful new way to work directly on the screen. Interactive “pen displays” (Figure 11) like Wacom “Cintiq” combine the advantages of an LCD monitor with the control, comfort, and productivity of tablet technology. By working directly on the screen, architects can navigate much more quickly and naturally and can sketch, draw, trace, and redline documents and drawings.
Architects can naturally create a sketch right on the computer and then quickly move through 2D layout and on to 3D modeling. Then using the latest 3D paint applications, architects can expedite 3D visualization to more quickly get to the next level of approval.
Sketch-based software like Autodesk Architectural Studio and SketchUp from @Last Software provides an innovative pen-optimized work environment for architectural artists and designers. When used with a “pen displays” the sketch-based approach is a powerful way to initiate the design process on the computer without giving up the design tools with which architects are familiar.
This sketch-based approach bypasses the process of scanning and tracing paper drawings and yet it doesn’t force architects to adapt to awkward technical drawing tools when creating freeform conceptual drawings.

6.4. Concept Development Applications That Aid in Producing New Concepts of “Genetic Architecture”

New free form curves sketching tools are aiding in development of new concepts. The program of **“Genetic Architecture”** in the Escola Superior d'Arquitectura (ESARQ) at Barcelona's Universitat Internacional de Catalunya (UIC) are using Rhinoceros software, a 3D

NURBS (nonuniform rational B-spline) software, as a tool for warped-surface visualization. "Genetic architecture" generates graphic and structural extrapolations to architectural design[28] by studying and mimicking life forms (biomimetics).

This linking of natural elements with digital production leads the students to create their own digital-architectural vocabulary based on, for example, cells, plants, shells, flowers, or rocks. From these natural components, they deepen their investigation of space enclosed by nonlinear forms (Figure 12). At the same time they study the related structure, branching, surface curvature, translucency, and so on.

These experiments involve rapid prototyping and stereolithography. Using a 3D Systems ThermoJet printer (Figure 13) installed at the school of architecture, students build physical models directly from their Rhino files. Student use of the ThermoJet printer also allows them to physically visualize aspects of their digital forms. The three-dimensional pieces serve to further their understanding of both positive and negative physical space as well as spatial relationships between architectural elements.

7. CONCLUSIONS & RECOMMENDATIONS

This study has reached several conclusions and recommendations. Following is a summary of conclusions:

1- Computerized synthesis --being the generation of formal design solutions with the aid of computers-- was traced back to 1963. It is, thus, one of the oldest applications of computers in architecture.

2- Studying the bibliography of computer applications in architecture shows that throughout the 1960s there were very heavy emphases on programs that aid the sketch design process. Relatively less emphasis went to visualization, drafting and database management. Today the situation is reversed. Relatively less attention is being paid for design-tools that help in the synthesis phase of the design process.

3- Although generative design tools were among the first applications that were developed to serve architecture, rather little application software has been commercially developed in this branch. Only lately, that there has been a notable increase in commercially available application software in this field.

4- It seems that the very slow development in artificial intelligence (AI) is the main technological obstacle facing generative design tools and the realization of the "Architecture Machine" as a comprehensive design-environments. In the 1970's people were overly optimistic about the possibilities of developing intelligence in computers. Fueling this optimism were some events. Among them was the robot that General Electric demonstrated which was "programmed" to answer some fixed questions. In addition, movies like "Space Odyssey 2000" in which an imaginary computer, called HAL, outsmarted many humans; further fueled this optimism.
The outcome of more than 3 decades of development, however, draws another picture that is not optimistic. Maybe nobody has phrased this better than Michio Kaku[29] of City University of New York when he said, in 2004, thatthe most intelligent machine that man has produced until now is no more intelligent than a crippled cockroach. Currently, computers are good in storing information and repeating routine tasks, but till now computers cannot recognize their environment, learn from experience or face non-routine tasks.

5- On the other hand, sketching and concept development tools seem to be developing rapidly. With heavy weight companies like Autodesk introducing products in this field.

6- Among both types of applications for form generation, the applications for concept development and sketching seem to be of greater impact on the profession and of greater practical use. This is measuring on the scale of problems each can currently handle.

7- The impact of networks and telecom is very clear in the transformation of many architectural computing applications through using networks into information technology applications.

8- The practical side is emphasized in all applications and only applications with potential to impact the profession are selected. Among the most important trends worth noting are:

   a- The emergence of tools that mimic the traditional architectural desk and tools.

   b- New interactive "pen display" hardware removes many of the boundaries between the architect and computer and achieves a hand-eye-coordination level near pencil and paper.

   c- The merger of collaboration tools with sketching and concept development software is producing a new breed of software that may be valuable in both education and practice.

   d- The emergence of easy to use flexible curve-modeling application software is facilitating the development of conceptual designs that rely much on curves and generated a trend of "genetic architecture".

   e- "Wizard" based generative systems are worth noting, as they carry out a dialog with the architect and collaborate and take turns with him in advancing the design one step at a time.

9- The comprehensive design environment is yet to be achieved. This computerized application would contain all the tools that an architect needs and would aid the architect. This is a recommended field for future research.

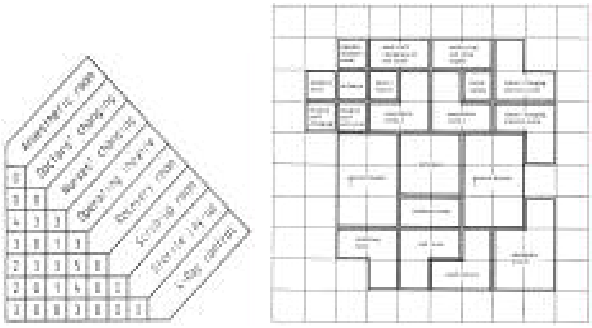
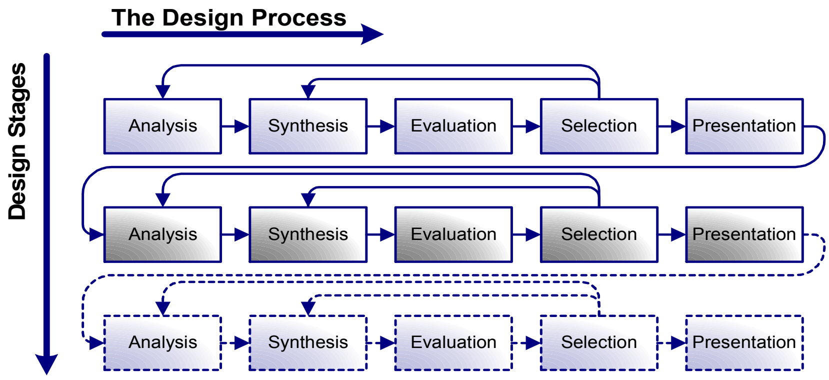


Figure 1. The Roots Of Generative Design-Tools. Layout Planning[8]: One of the early attempts to use computers as a generative design aid. The goal was to minimize the cost of movement of the users of the building between different spaces. The strength of relationship between each two spaces is represented by the number of trips between them in the matrix.

Figure 2. The Roots Of Sketching and Concept Development Tools. Ivan Sutherland at the console of the TX-2 - Sketchpad Project, MIT, 1963. The display, a lightpen, and a bank of switches were the interface on which Ivan based the first interactive computer graphics. In 1963, his Ph.D. thesis, "Sketchpad: A Man-machine Graphical Communications System," used the lightpen to create engineering drawings directly on the CRT[30].

Figure 3. Synthesis in the Heart of The Design Process: The five steps[17] operate cyclically and are not performed rigidly. In real life, creative design may break some rules, objectives may be redefined and new weighting factors may be assigned.



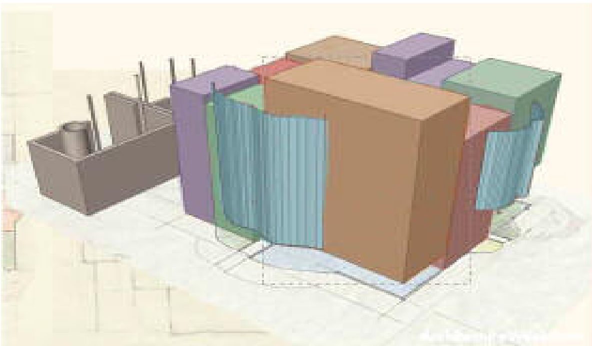


Figure 4. Sketching and Concept-Development Tools From Tracing Paper To 3D. A plan sketched by hand on tracing paper then scanned and used as a template to build a 3D model in Architectural Studio. (by Cornell student Yasemin Kologlu[27])

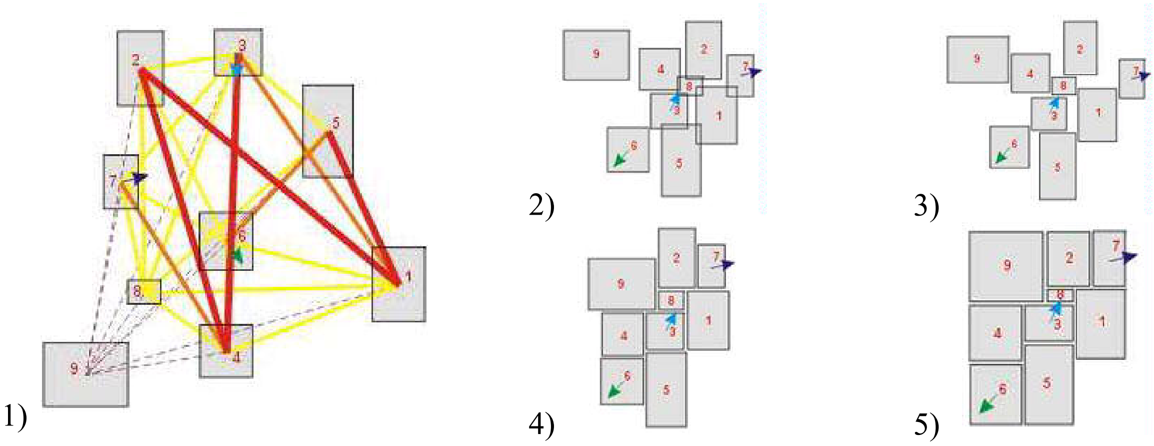


Figure 5. Generative Design Tools That Use The Laws of Physics to Generate Plans. The Innovative Space Planning Tool[23] works as follows: 1) Randomly positioned spaces are pulled apart and pushed together according to program requirements. 2) During the simulation, the spaces move to their proper orientation, but some spaces temporarily overlap. 3) A middle step of geometric resolution removes overlaps, but the gaps between spaces remain. 4) As the designer interacts with the simulation, the gaps are removed, and spaces relocated. 5) Finally, the spaces are grouped in a viable floor plan with aligned exterior edges.

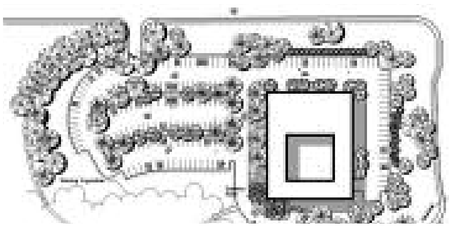


Figure 6. Specialized Generative Tools: e.g. Parking Lot Layout Tool[24]. This tool helps the designer create the geometry for a variety of parking configurations.

Figure 7. Wizard Based Generative Tools are Starting to be Mainstream. One of Chief Architect's software newest features is the "House Wizard[25]," a space-diagramming tool capable of doing preliminary massing for houses.

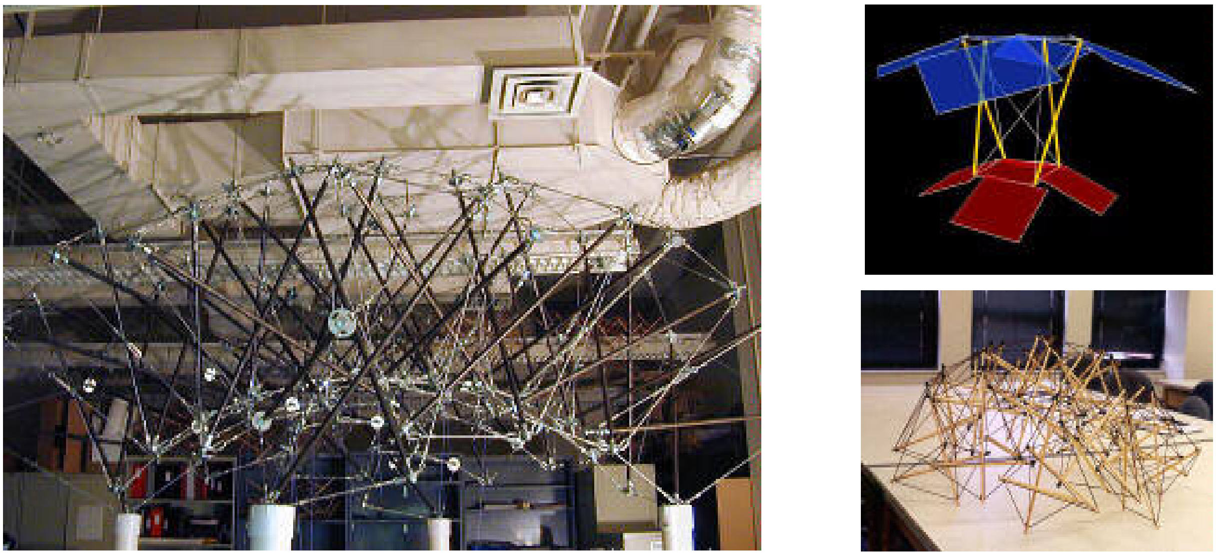


Figure 8. Generative Tools That Aid in Developing New Structure Systems. A parametric model[26] developed by Katharine Liapi at the University of Texas allows architects to visualize and design with tensegrity structures

Figure 9. Mimicking the Conventional Desk And Conventional Tools Like Pencil And Tracing Paper. The screen can be filled with imagery from many sources: scanned photographs and hand-drawn sketches, drawings imported from other projects, stacks of alternative concept sketches, renderings, and GIF animations. With the tracing-paper tool[27], architects can overlay translucent "trace" and develop new variations of a design while preserving old ones. This also allows sketching in 3D

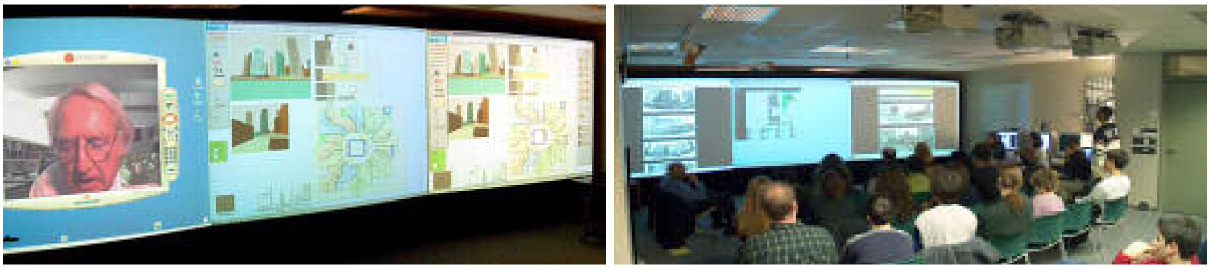


Figure 10. Collaboration in Form-Generation by Combining Sketching and Concept-Development Tools with Video Teleconferencing. An architecture studio at Cornell participates in a review with professionals several hundred miles away. During a videoconferencing session with architect Richard Meier, students watched him draw and critique student work[27], using Autodesk Architectural Studio.

Figure 11. Enhancing Sketching and Concept-Development and Hand/Eye Coordination by Interactive "Pen Displays". By working directly on the screen, architects can navigate much more quickly and naturally and can sketch, draw, trace, and redline documents and drawings.

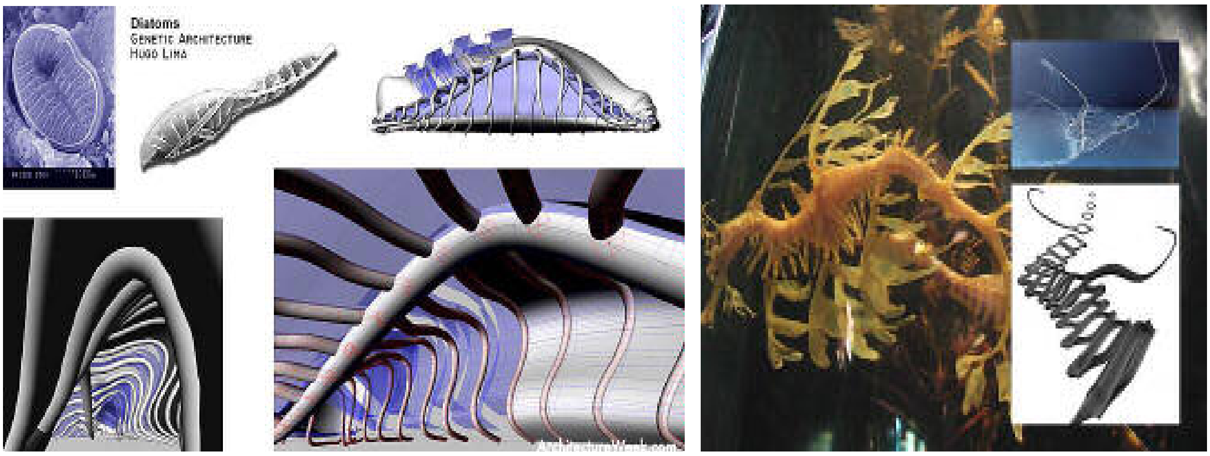


Figure 12. Sketching and Concept-Development That Aid in Developing New Concepts Using Flexible Free-Form Curve-Creation Tools. This results in linking of natural elements with digital production using rhinoceros[28] software and leads the students to create their own digital-architectural vocabulary based on, for example, cells, plants, shells, flowers, or rocks.

Figure 13. Taking Sketching and Concept-Development One Step Further By Transforming Concepts Into Tangible Prototypes. Rapid Prototyping And Stereolithography[28] Using A Thermojet Printer. Students build physical models directly from their Rhino files. (The top insert shows the build chamber while the bottom shows a model during the cleaning process to remove supports.)

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