Designing by Simulation
Computer Aided Design

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This article evaluates 'simulation' as a contributing factor in architectural design. While computers enhance simulation, they have yet to transform the art of architecture. A partial explanation is found at the extremes of design processes: Gaudí's Sagrada Família Cathedral of Barcelona is an empiricist's culminating achievement -- faith expressed in stone. By contrast, SOM's Sears Tower of Chicago is the modernist monument to rational process -- (financial) faith engineered in steel and glass.

Gaudí employed an understanding of the heritage of stone and masonry to fashion his design while SOM used precise relationships of mathematics and steel. However, the designs in both the Sears Tower and Sagrada Família are restricted by the solutions inherent in the methods.

In contrast, student designs often have no inherent approach to building. While the solution may appear to be evident, the method must often be invented; this is potentially more costly and complex than the design itself. This issue is not new to computers, but its hyper--reality is potentially more complex and disruptive.

In evaluating the role of computer simulation in architectural design, this article employs two methods:

1. Exoskeletal design: A limited collection of connected plates is formed and designed through warping, bending and forming. Reference architect Buckminster Fuller.
2. Endoskeletal design: Curtain wall construction is taken to its minimalist extreme, using pure structure and membrane. Reference artist Christo.

Diseño por Simulación.

Este artículo evalúa la "simulación" como un factor contributivo al proceso de diseño arquitectónico. Mientras por una parte el uso de la computadora estimula la simulación; por la otra, aun tiene por delante la transformación del que hacer arquitectónico.
Una explicación parcial de lo anterior se encuentra en extremos existentes dentro del proceso de diseño. La Iglesia de la Sagrada Familia en Barcelona de Antonio Gaudi es la culminación de los logros de un empírico - fe expresada en piedra-, en contraste la Torre Sears en Chicago de la firma S.O.M., es un monumento modernista al proceso de razonamiento (financiero) - fe organizada en acero y cristal-.
Gaudi mostró el entendimiento de la tradición del trabajo de la piedra y el uso de la mampostería para confeccionar su diseño, mientras que por su parte S.O.M. hizo uso de la precisa relación entre las matemáticas y el acero. Sin embargo, en ambos casos los diseños se vieron restringidos por las soluciones intrínsecas de los métodos utilizados para su realización.

En contraste, los diseños de estudiantes carecen de este tipo de acercamiento intrínseco hacia la construcción. Mientras la solución podría parecer evidente, con frecuencia el método debe ser inventado; resultando potencialmente mas costoso y complejo que el diseño mismo. Este hecho no es nuevo para el uso de la computadora, pero su hiper realidad es potencialmente mas compleja y disruptiva.

Dentro de la evaluación del papel de la computadora en la simulación del diseño arquitectónico, este artículo hace uso de dos métodos:

1. Diseño Exoesquelético (Exoskeletal Design): Una colección limitada de conexiones de placas formada y diseñada a través de envolturas, dobleces y formas. Referencia, Arquitecto Buckminster Fuller.
2. Diseño Endoesquelético (Endoskeletal Design): La construcción de muros de revestimiento es llevada a un extremo minimalista haciendo uso puro de membrana y estructura. Referencia, artista Christo.

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The Virtual and the Real (What is the problem?)

It has been brought to my attention by students and professional architects alike that the computer as a form giver of architectural reality has demonstrated one unexpected shortcoming: an apparent inability to contribute to or influence the integration of aesthetic judgement and critical design function in the world of real architecture. While the virtual real-estate of Internet commerce (new urban landscape and place) is experiencing explosive, unfettered growth in virtual shopping malls, libraries and entertainment arcades, digital technology appears unable to creatively engage real architectural design. This brings the whole issue of Computer Aided Design under increased scrutiny and controversy.

There are exceptions to this generalization; architect Frank O. Gehry's design of Museum of Modern Art in Bilbao, Spain was partially dependent on the computer. He used digital means to interpret clay models of the proposed building. Gehry also found the computer essential to coordinate the many complex design conditions – but only in the engineering, product management sense – not in the conceptual creative effort. In Gehry's process, the initial design is conceived through drawings and models that are interpreted through various computer-tracing programs into forms that are then managed by computer.

To a greater or lesser extent, this hybrid design method is in place in almost all modern architecture. Contemporary design in the late twentieth century architecture includes computer use for structural engineering calculations, environmental impact, energy management, visualization, and ubiquitous document creation and coordination. At this juncture, architectural designers have timidly crossed into the realm of computer aided design, leaving CAD's potential of real world creative expression in architecture unfulfilled.

I propose that there are two distinct causes, one financial involving market forces and one technical concerning methodology. However, for the sake of clarity, the terms 'architecture' and 'CAD' must first be defined.

Architecture and CAD

If Computer Aided Design is simply the assemblage of parts, visual displays and automatic delivery of construction documents, then CAD is on its way to becoming a universally successful phenomena. However, the term Computer Aided Design as coined in the marketing pitch of the software manufacturers is not synonymous with artistic creation. Therefore, I am supplying the following definition of Computer Aided Design:

> *Computer Aided Design (CAD) begins at the Design Threshold where processes of design and architecture become a singular consideration. It is engaged when:*
> *1. The digital process becomes integral to the conclusion, a design that would not have been reasonably anticipated otherwise.*
> *2. The intention of the designer is substantially dependent on the interaction of digital process to accomplish the intended result.*
> *3. The complexity of the task exceeds the ability of the designer to accomplish that task by any other reasonable available means.*

Building Art and Function

Louis Sullivan's Chicago School 'Form Follows Function' is evident in mainstream use and common acceptance as seen by its use in commercial automotive advertising. However, as an architectural principle, even when loosely construed, it tends to exclude building art from consideration. Nevertheless, with slight alteration, I have redefined the intention of architecture to address the relevant issues in this discussion:

> *Architecture consists of 'Building Art and Function', as differentiated from 'Form and Function.' The difference is not intentionally semantic. The inclusion of building art is not a political stand but an acknowledgement of the requirement to include artistic intention in addition to any requirement of function. This non-judgmental inclusion is particularly necessary with respect to past and potential future trends in architectural design. Contemporary accounting procedures, especially value engineering, address this area of design.*

Tenets of the Financial Markets (Cause 1)

Patrons of present day corporate architecture have a different perspective than the patrons of past architecture. Today, corporate culture dictates that commercial architecture respond to the needs of the investor. This creates a separate entry on the balance sheet. As with all investments, corporate art as architecture must meet the needs of the corporation. This is clearly an acceptable cost factor for design in an entertainment company like Disney or an image conscious client like Mercedes-Benz. For a more typical client however, design is often identified as a cost issue that is frequently value engineered out of the architecture. Although the tenets of Capitalism are beyond the bounds of this discussion, a functioning market place will be considered as a design factor.

Simulation, Means, and Design (Cause 2)

Practitioners of Computer Aided Design have yet to pass beyond the Design Threshold and engage factors one and two stated above. This is essentially an artistic/technical issue (with financial overtones). The resolution may require a restructuring of design thought, but we are not really dealing with factors that are radically different or without historic precedent. The problem originates when design gestures in the computer are essentially impossible to realize. Designers that operate at the margins of expression with unrestrained visual vocabularies have not considered the issue of translation. The language of expression (lines, surfaces and forms) must be deciphered into reality. Unfortunately, a compelling visual gesture often transforms into an unrecognizable facsimile of the original design intention. These efforts ignore Louis Kahn's axiom of 'asking a brick what it wanted to be'. No bricks are found in this world of electronic desires, only dreams and dreams are difficult to build.

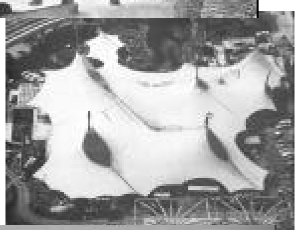
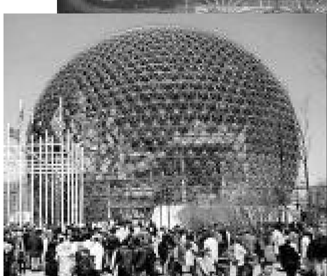
> **'Architectural Genus'** *adapted from: ge-nus (jee'nuhs) n. pl. <gen-e-ra>(jen'uhr uh) <ge-nus-es> 1. the usual major subdivision of a biological family or subfamily in the classification of organisms, usu. consisting of more than one species. 2. Logic. a class or group of individuals, or of species of individuals.*

I have borrowed the term genus to address a similar situation to the one that Kahn faced with the brick. The virtual equivalent of a brick is a consideration in Computer Aided Design that should be dealt with before or at least in conjunction with the stated architectural objective. Masonry, glass, steel, plastics and the organic and inorganic materials yet to be developed when used individually or in combination are the 'bricks' to build our dreams.

Simulation, Primary Design Considerations

The following matrix identifies the primary conceptual considerations involved in design development. Other factors may be employed in the design, however they are not primary determinants of form. In all cases, the Genus of the architecture, the method employed in simulation, is a critical factor. This chart reflects historic, transitional (the computer as a limited participant) and proposed computer aided approaches to architectural design (engaging issues beyond the Design Threshold).

simulation

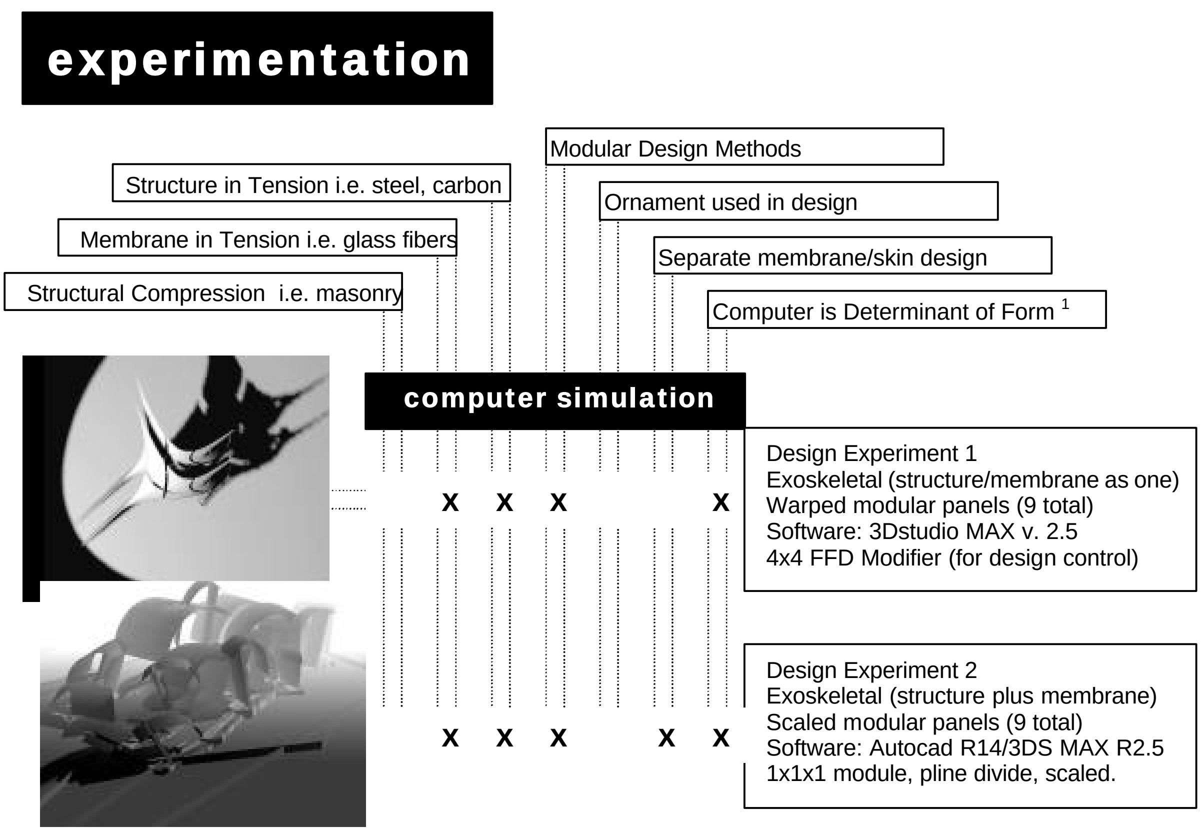

Project	Structural Compression i.e. masonry	Membrane in Tension i.e. glass fibers	Structure in Tension i.e. steel, carbon	Modular Design Methods	Ornament used in design	Separate membrane/skin design	Computer is Determinant of Form [1]
empirical simulation							
Architect: Antonio Gaudi Colonia Guell, 1898, 1908-1915 Location: near Barcelona, Spain Building Type: church crypt Brick and stone masonry	X			X	X		
Architect: Frei Otto German Pavilion, Expo '67, Montreal, Canada, 1967. Membrane fabric roof, tensile structure		X	X	X		X	
Architect: Buckminster Fuller and Shoji Sadao US Pavilion at Expo '67, at Montreal, Canada, 1967 Geodesic dome, transparent membrane		X	X	X	X	X	
Artist: Christo Valley Curtain, Date 1971 - 1972 Rifle, Colorado Steel cable, fabric curtain		X		X		X	
hybrid simulation							
Architect: Bruce Graham/ SOM Sears Tower, Date: 1974 to 1976 Location: Chicago, Illinois Steel frame with glass curtain wall	X		X	X		X	X
Architect: Frank O. Gehry Bilbao Guggenhiem Museum, Oct., '97 Location: Bilbao, Spain Titanium skin, steel frame			X	X		X	X

How Does Simulation Affect Design?
The above examples all have one thing in common: it is that the solution in the built form is inherent in the process – even before the design was considered. The Sears tower is fundamentally a civil engineering solution of the endoskeletal type whose bones support a lightweight aluminum and glass curtain (skin). The use and capabilities of structure and skin allowed a high level of self-assuredness in design predictability and performance. The flexible design performance of each module allowed virtually endless repetition. Similarly, the module of Fuller's geodesic dome allowed similar repeatability. The limitation of this approach is that these modules are regular. The question then becomes what is the nature of regular modules and what would be the consequences of irregular modularity?

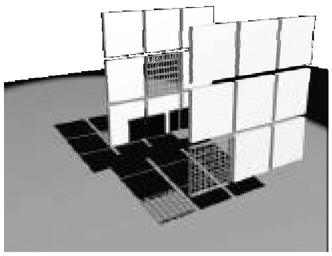
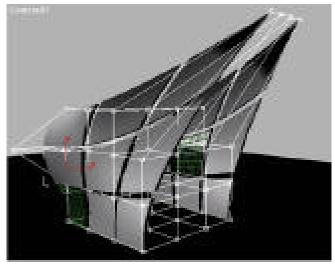
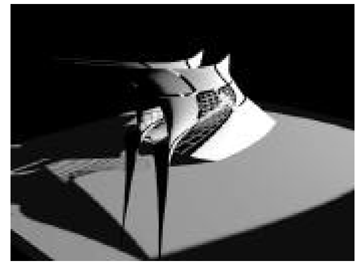
Irregular expressions are evident in Frei Otto's tent like experiments, Gaudi's Colonia Guell and Frank Gehry's Bilbao Museum. These solutions were arrived at through empirical design investigations. The design principle was established through experimentation and the projects were modeled through traditional (although ingenious) methods. Only Gehry's required the use of a computer, but only to manage building complexity, not conceptual design. The question then is, can empirical design methods be developed within the computer that allow for simultaneous conceptual design and building design.

The Experiments
In evaluating the role of computer simulation in architectural design, two methods are considered with respect to their potential to simulate and effectively engage real world situations.

1. Exoskeletal design: A limited collection of connected plates is formed and designed through warping, bending and forming. Reference: architect Buckminster Fuller's geodesic dome at EXPO 67 for regular modularity and Gaudi's Colonia Guell for irregular modularity.
2. Endoskeletal design: Curtain wall construction is taken to its minimalist extreme, using pure structure and membrane. Reference: artist Christo's Royal Gorge Curtain for the ultimate artistic expression, Frei Otto's EXPO Pavilion for a functional aesthetic and the Sears Tower for the ultimate commercial exploitation.



Design Components and Predictability

The general concept is that modular components of known quantity and type are acted on by force modifiers, a mathematical alteration based on visual interaction (utilizing rule one and two of the Design Threshold). The modules (irregular in this case) all have four points to transfer forces to the adjoining plates. The plates are of known size, composition, and physical properties. The performance of the plates including thermal properties, photovoltaic potential, life cycle costs, environmental impact etc. are evaluated at the modular and the building level. The above example is of the endoskeletal type where the structure and the skin act as one. Experiment two involved structure and skin of a unit modular construction (1x1x1) that was scaled separately in the vertical and horizontal dimensions. In each of these cases, a complete engineering solution is inherent at the modular level and is transferred to the collective composition. These two experiments are representative of an 'architectural genus', they are not intended to limit design investigation, but to encourage innovative investigation.

The Solution is Inherent in the Process

Frei Otto's tensile fabric structure experiments (left) and Gaudi's sandbag weighted wire models appeared distant from the reality of building when first proposed. However, the development of sound methodology through empirical study resulted in buildable architecture. Frei Otto's empirical concepts were exploited in the US EXPO 67 building and later in public buildings and airports. Gaudi's wire models were determinants of the method to construct Colonia Guell and later to inform his defining work, Sagrada Família Cathedral. SOM's Sears Tower was the culmination of prototypical design techniques that were brought to reality through careful study and a clear understanding of precedent and method. However, while all of the above are a culmination of processes of simulation, none could have resulted from the other methods.

Both the Sears tower and Gehry's Bilbao Museum are the first efforts that could not have been built by 'any other reasonable available means' – a computer was needed in structural and building calculations – but that alone is a far cry from 'design'. When evaluated from the 'Design Threshold', Computer Aided Design has yet to take hold. In summary, Computer Aided Design when implemented as a visual gesture – even a carefully constructed and observable model – is essentially a foreign document in the language of construction. The CAD model is a document in need of translation, and herein lies the problem.

Since the components of orthogonal construction can be bought 'off of the shelf', uninspired designs imposed by packaged software will continue to find a willing market. Perhaps the essence of corporate architecture and financial accountability require business warehousing and that is not a problem. However if change is desired, and computers are part of that vision, the graphic display must become more than a cosmetic intention.

It is unclear what the future holds in the way of computers and design 'in the real world,' but there is compelling evidence that technology is not exempt from the lessons of history. Simulation, whether in the real world or in the computer, requires solutions that are inherent in the process.

[1] Flanagan, Robert. "The Design Threshold." II Seminario Iberoamericano de Grafica Digital, 1998

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