Skin: Sensory Accountability

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I can see love

I can hear love

I can taste love

I can touch love

I can smell love[1]

SKIN: SENSORY ACCOUNTABILITY IN DIGITAL DESIGN

The general nature of this paper is to address skin as a regulatory device of sensory experiences in architecture.[2] The specific intention of this study is to investigate the relationship of digital technology with the various manifestations of skin and structure in building design.

While the computer is a powerful investigative tool, its development is hindered by the inherent inflexibility of its pre-programmed nature;[3] therefore, carefully defined rules that exploit a computer's strength—the visualization and placement of membrane (skin) and structure—must be observed. The rigidity of the computer's approach introduces weaknesses into the design process; the complex, non-visual properties of skin resist integration with the digital model, creating gaps. In the design approach proposed later in this paper, these gaps (resulting from the elimination of processes in design development) are evaluated with an eye toward reintegration through adaptations in digital design process (at the direction of the designer).

These concerns are not isolated technical issues; there is an implicit acknowledgment that digital technology operates in the larger sphere of social, economic, religious and political order. Historically, sensory experiences were, in fact, inextricably designed into centuries of spiritual architecture. It is proposed here that one consequence of the scientific method, the development of which accompanied the expansion of the Industrial Revolution, was the realignment of human values in a way that continues to the present to marginalize non-visual sensory experiences. In a later discussion of modularity, issues of sensory accountability are evaluated and addressed, but there is no impending expectation of a social realignment that would reestablish the multi-sensory significance that evolved in the era of spiritual architecture. These modest proposals of sensory integration are intended to demonstrate digital design principles, regardless of the requirements of economic function.

The premise of 'sensory accountability' is that all five senses of the occupant, sight, sound, touch, taste and smell are potentially regulated by the attributes of a building's skin. Here, sensory accountability is addressed (with a remedial bias) in the schematic design phase through adaptations of process – specifically introducing sensory accountability into modular adaptations of the digital design process. The proposed strategies do not cure the problem; they are intended to ameliorate deficiencies in the design process. The approach therefore is to:

1. examine precedent of sensory design and accountability in architecture,

2. evaluate the circumstances of digital technology's visually dominant design approach, and the corresponding immaturity in non-visual sensory design development,

3. establish a cross-referenced matrix to contextualize the phenomena of skin and structure in post-Industrial Revolution architectural design, and

4. propose digital design strategies with the potential to foster sensory accountability.

ARCHITECTURE: A MINIMALIST GESTURE

Architecture's sole determinant is the physical manifestation of skin and structure.[4] While this definition is unquestionably severe, it is capable of accommodating a wide swath of historical precedent. It also facilitates the digital aspects of this investigation. In these minimalist terms, the purpose of (building) skin is to control and to regulate sensory perception of the occupant while the purpose of structure is to locate the skin in space; Bernard Cache (in *Earth Moves*) refers to a relationship where "architecture becomes a clothes hanger." In pre-Industrial Revolution civic and religious architecture, advanced masonry (compressive) design was highly evolved; there was not, however, a corresponding structural (tensile) sophistication.[5] Pre-Industrial Revolution architectural concepts are helpful in framing the social/technical context of this discussion, but post-IR relationships of structure, membrane and economics will define the digital design experiments at the end of this discussion.

THE MYSTICAL ART OF SENSUAL DESIGN

In the pre-Industrial Revolution era, sensory experience was the intended function in high architecture; elaborate multi-sensual design infused the architecture of the medieval cathedral.[6] The sound of the choir resonated His praise. The smell of incense venerated His glory, a sense-perceptible gift to the Deity as an outward manifestation of our veneration for Him and with the object of attaining communion with Him.[7] The touch of baptism remitted sin; be baptized and wash away thy sins.[8] The light of the world was the light of God;[9] God divided the light from the darkness.[10] The taste (and touch) of bread and wine accorded redemption, He that eateth my flesh, and drinketh blood, abideth in me, and I in him (John, vi, 57).[11]

> *Consecration is a rite reserved to a bishop, who by the solemn anointing with holy chrism, and in the prescribed form, dedicates a building to the service of God, thereby raising it in perpetuum to a higher order, removing it from the malign influence of Satan, and rendering it a place in which favours are more graciously granted by God.* - By a decree of the Council of Trent (Sess. XXII).[12]

At the moment of Consecration, the secular materiality of place was transformed into the seamless spiritual device of salvation. It was an age of miracles and mysticism, a time when penitents petitioned God, prayed to the Saints, were watched over by Angles, and were filled with the Holy Spirit.

SECULAR REALIGNMENT

The phenomena[13] of sacred space prevailed for more than a millennium, but time and circumstance cloud the search for a specific marker or event to signal its demise. "Galileo was summoned by the Inquisition in 1632, tried, and on June 21, 1633, pronounced 'vehemently suspected of heresy'."[14] He was excommunicated by Pope Urban VIII in 1633 on the basis of his scientific pronouncements; Pope John Paul II eventually reinstated him – three hundred and fifty years later. It is notable that technical, economic, political and religious factors do not evolve on parallel timelines. It is also necessary to recognize that an architect's intentions and desires do not necessarily result in material facts.

The specialization of labor and production, which characterized the Industrial Revolution, paralleled specialization in design and function; sacred architecture was not so much replaced by secular architecture as it was overwhelmed by it. Predictably, the advantage inherent in the specialization of function culminated in the extreme architecture of the twentieth century, an era of gigantism.

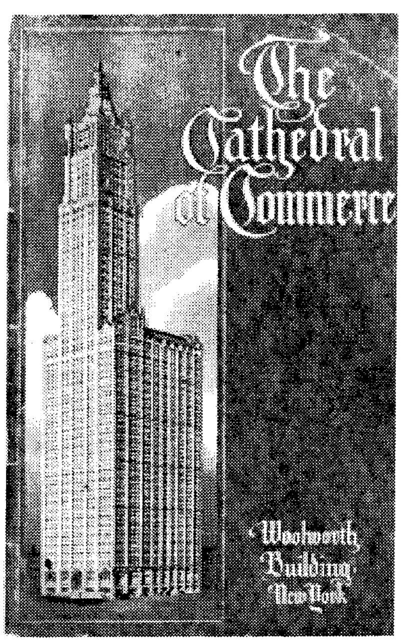

Fig. 1. The Woolworth Building, 1917

The Woolworth Building was consecrated a new *Cathedral of Commerce*, espousing the philosophy, "Just as religion monopolized art and architecture during the Medieval epoch, so commerce has engrossed the United States since 1865."[15] The new secular architecture relied on the laws of thermodynamics, and not Consecration.[16]

REFLECTIONS ON THE 20TH CENTURY IDEAL, DESIGNING THE DESIGN PROCESS

Visual design was the only advanced sensory design capability, regularly employed in architecture, that endured the secular eclipse of sacred architecture. Today, the creed of capitalism prevails. Sound, if it is considered, is usually deadened. Smell is generally eliminated and almost never introduced intentionally, eateries excepted. Touch is a commodity level concern i.e. doorknobs. Taste is generally not a consideration. The breeze through an open window, the smell of a meadow, the sound of rain, or the taste of ocean spray: if, in contemporary, commerce-driven architecture, any value is assigned to these sensory experiences, it is a negative one. These sensations are distractions in the world of commerce.

THE ARCHITECTURE OF DENIAL AND THE NARCOTIC EFFECT

Since the elimination and restriction of multiple sensual experiences is often deliberate, it is helpful to differentiate the unintended from the deliberate denial of the sensory experience. In one instance, design inexperience compounds the visual preoccupation of digital media. But more commonly, visual control is the objective; sensory denial is imposed through digital media with a corresponding desire to focus and enhance productivity.

The denial of sensory awareness is often accompanied by an obsession with visual control (the aesthetic). "The emphasis on the visual display overwhelms and intoxicates the viewer."[17] It can intoxicate the designer as well. Neil Leach proposes that a 'narcotic effect' is induced by a visual, aesthetic obsession in design. "Architects, it would seem, are particularly susceptible to the aesthetic that fetishizes the ephemeral image, the surface membrane."[18] While the fetishization of skin as a visual control device is a comparatively recent architectural phenomenon, it is rooted in the Industrial Revolution's infatuation with technical specialization. This specialization of technology cleared the way for the ascendancy of an Endoskeletal Model characterized by the systemic disengagement of structure from skin. This was a propitious development since the ability to design and incorporate visual control is optimized when skin functions as a highly specialized membrane.

The specialization of technology encouraged the evolution of discrete functions evident in this Endoskeletal Model and ideally suited to the exhibition of skin as the primary aesthetic. In the present day, skin's minimal functional requirements may be distilled into the following: transparency (acceptance or denial), thermal properties, and cost.

THE REVOLUTION OF THEORY AND PRACTICE

Since the Industrial Revolution, skin and structure have co-existed in one of two primary configurations, those that depend on internal frames, and those that require external frames. In the first and most common configuration, the Endoskeletal Model, the skin (membrane) is positioned and supported by an autonomous frame. In the second, external configuration, the Exoskeletal Model, membrane and structure act in concert and share function (structural membrane). In the real world of architecture, these models are often used in combination, but one of the systems is generally identifiable as predominant.

The only apparent relationship between the pyramid of Cheops (2500 BC) and I.M. Pei's pyramid at the Louvre (1989) is one of form. While their political, religious and economic origins are entirely different, as are their technologies, materials, and functions, it is the relationship of skin and structure that is the common (or uncommon) essence of their architectural existence. The masonry construction at Cheops functions as a composite structural membrane in an exoskeletal configuration. In contrast, I.M. Pei's steel and glass pyramid at the Louvre employs an autonomous structure protected by a separate envelope (membrane/skin) in an endoskeletal configuration. Regardless of the apparent visual similarity or lack of similarity in these forms, their architectural character is derived from the five sensory control properties of their skin: sight, sound, touch, taste and smell.

REGULAR MODULARITY

Twentieth century Modernist design, especially in cities, predominately conforms to an Endoskeletal Model, where curtain-wall skins are affixed to internal structures. These curtain-walls are commonly fabricated from orthogonal, repeating modules of metal and glass. While stylistic preference for unadorned skin became the emblematic marker of Modernism, it was manufacturing efficiencies and the specialization of function (separate membrane and structure) developed during the Industrial Revolution that allowed Modernism generally, and the Endoskeletal Model in specific, to flourish.

The Sears Tower's predominant configuration is as an Endoskeletal Model; its discrete structure and skin are assemblages of regular modularity. If the application of scientific and mathematical principles to model highly specialized materials is the criteria, the Sears tower is a marker of excellence in Industrial engineering. Alternately, the 'low-tech' regular modularity characterized by Exoskeletal pre-cast concrete systems, fulfills commodity applications demanded of architecture. These mass-produced modules may be less flexible in design and application, but their demand in many design applications has escalated on account of their exceptional cost effectiveness.

IRREGULAR MODULARITY

Irregular modularity has experienced a more limited application. The exotic complexities of its non-linear engineering calculations confound building codes, while the unfamiliarity of its construction techniques, coupled with unfamiliar materials, results in prohibitive cost. Its major liability however, is the fundamental incompatibility of its non-rectilinear systems in a predominately linear built environment.

There are exceptions. Antoni Gaudí overcame the engineering limitations imposed by traditional linear mathematics in his *irregular (masonry) module* through inventive use of wire and sand weighted engineering models (Exoskeletal design). Architect Frei Otto's German Pavilion at Expo '67 celebrated non-linearity with a dynamic tensile cable structure that supported a fabric roof, in a demonstration of *irregular modularity* (Endoskeletal design). Also of note is architect Eero Saarinen's Gateway Arch in St. Louis; the tapered, stainless steel arch employs *irregular modularity* in an Exoskeletal configuration.

A fiberglass boat hull, a block wall and a reinforced concrete elevator core may appear unrelated, but the simultaneous mission of membrane and structure categorizes their exoskeletal anatomy. Alternately, a cable-stayed tent structure, a curtain wall and an airplane fuselage derive their endoskeletal identity from the discrete functions of structure and skin. In a system reminiscent of the evolutionary forces that impose their will on nature, the economics of function dictate the evolution of structure and membrane.

DESIGNING BY SIMULATION

The process of 'simulation' is yet another integral factor in architectural design – a cornerstone of traditional design and the essence of digital design. While computers significantly 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 in Barcelona is an empiricist's culminating achievement—faith expressed in stone. By contrast, SOM's Sears Tower of Chicago is a modernist monument to rational process—(financial) faith engineered in steel and glass.

While Gaudí employed an understanding of the heritage of stone and masonry to fashion his design, SOM created precise relationships of mathematics and steel. While vastly different in approach, the design possibilities of both the Sears Tower and the Sagrada Família are restricted by the solutions inherent in their design simulation and building processes.

The Sears Tower is fundamentally a civil engineering solution in an endoskeletal configuration, with structure in support of a lightweight aluminum and glass curtain (skin). Understanding the precise engineering characteristics of structure and skin permits a high level of design predictability and performance; the flexible design characteristics incorporated into each module allow virtually unrestricted repetition. The building form, however, is limited to allowable design permutations and combinations of the regular module.

The irregular modules expressed in Frei Otto's tent-like forms, and Gaudí's irregular masonry module (Colonia Guell for example) required significant empirical design consideration. Frank Gehry's Guggenheim at Bilbao employed a computer to manage the complexity of design development, but not design itself. This is an expensive and imprecise design relationship; Ghery's process only engaged the Digital Design Threshold (see below) condition #3 (The complexity of the task exceeds the ability of the designer to accomplish that task by any other reasonable available means).

DIGITAL DESIGN, CONTEXT AND DEFINITION

The question then is, can empirical design methods be developed within the computer that allow simultaneous conceptual design and building design; can computers enhance the design process and not simply be instruments of assemblage, validation and documentation? In order to quantify this goal, Digital Design is defined in terms of a threshold, a point where the computer and the design process become inseparable.[19] Any one of the following requirements would establish a threshold condition, 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; and/or

3. the complexity of the task exceeds the designer's ability to accomplish it by any other reasonable available means.

CONFIGURATIONS OF MEMBRANE AND STRUCTURE, A HISTORICAL PERSPECTIVE

Means and methods, using examples of design development from prototypical twentieth-century architecture, classify this matrix of skin and structure (Figure 2).[20] In the traditional-empirical design methods illustrated above, design is not computer dependent; however, the architecture is illustrative of the significance of creativity in 'simulation' in the realization of innovative design. In the bottom section of Figure 2, the design methods are computer dependent, but the computer technology is primarily concerned with validation. The computer does not engage the designer; it validates complex engineering and building calculations, satisfying only condition #3 in the 'Design Threshold' definition.

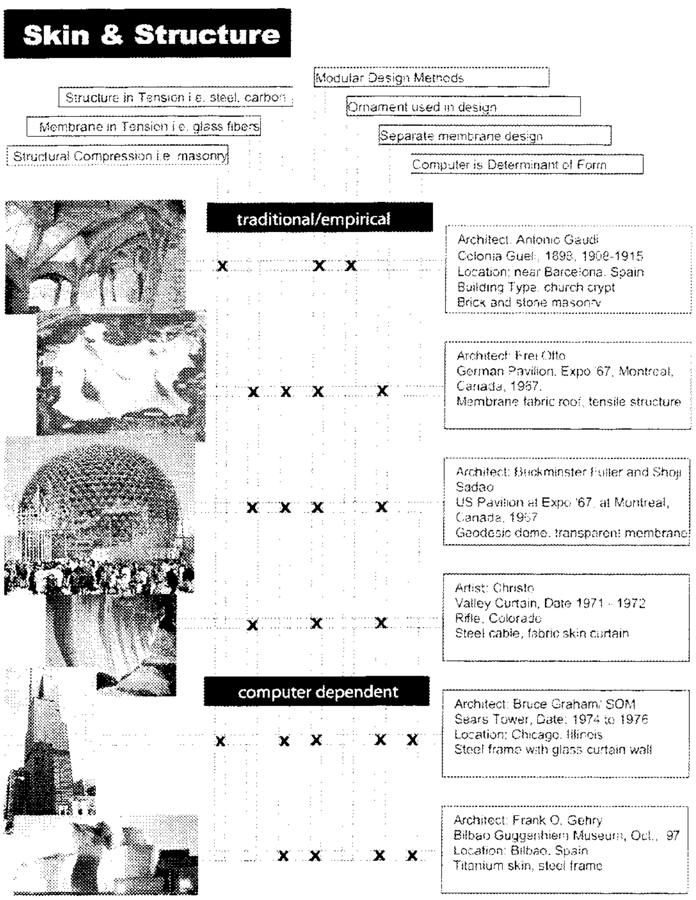

Fig. 2. 20th Century Membrane-Structure Matrix

THE EXPERIMENTS

A critic's evaluation of the processes of architectural design and analysis is, by its nature, subjective. An inference can be drawn, however, that successful innovation in architecture involves the identification of a problem, the development of an approach to deal with that problem and the validation of that approach through simulation. The problem identified here is two fold: digital design has evolved into a visually obsessive media event (often at the expense of other sensory considerations) within a visually obsessive culture; and the condition is exacerbated by an inflexibility in preprogrammed linear logic, [21] limiting the useful interaction between the architect's imagination and 'machine intelligence'. As a consequence, digital simulation faces intractable complexities when attempting to translate an ethereal, virtual concept into real world design, except as a stenographic stage set. These claims, on their faces, appear to contradict the success implied by the explosion of digital design publications. While virtual galleries of multi-dimensional and hybrid worlds abound, the assumptions of pending digital design application is at odds with the digital design void[22] in the world of built architecture.

In the limited proposition offered here, a straightforward demonstration of principle was the goal. A useful digital design process would identify the means to directly respond to non-visual, sensory accountability concerns. It would have the capacity to be the primary determinant of form and space *and* to efficiently translate design simulation into application. It would actively engage the designer's intellect and intuition with the embedded intelligence in the machine.

Experiment #1: Design, Simulation and Modularity—The Exoskeletal Model

In Experiment 1 (Figure 3) sensory accountability is addressed in the schematic design development phase with design simulation at the modular level. An Exoskeletal assemblage of arrayed plates is subjected to modification in the flexing, warping, and bending of form; its intent is to promote the interactive bond between architect and 'machine intelligence'. The process aims to avoid the quagmire where the means and method are selected to best represent design intention (design before method). Instead, means and method are pre-established; design and simulation represent the same circumstance (method before design).

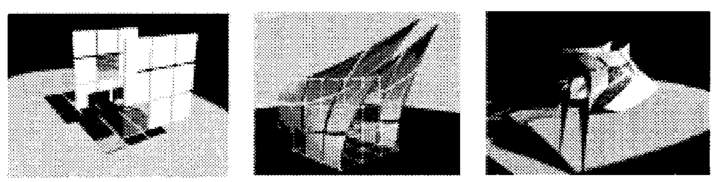

Fig. 3. Exoskeletal Model Simulation

Transformation of regular into irregular modularity maintains a direct relationship between computer simulation and building form. These design processes fuse the manipulation of *free form deformation*[23] modifiers with the designer's visual judgment in an interactive virtual environment. The digitally enhanced iterations are essentially instantaneous, accompanying a translation of computer gesture into form of known properties, quantity and type. The process engages rules one, two and three of the Design Threshold. The design would not have been anticipated by other reasonably available means; the intention of the designer is substantially dependent on the interaction between designer and machine; the complexity of the task exceeds the ability of the designer to accomplish the task by any other reasonably available means.

Simulation in this virtual environment is representational; the materials and forms that they model do not need to be invented. In this interactive mathematical simulation, the design characteristics of the individual module bracket the design potential of the building form (weakest link). Performance characteristics, including sensory accountability, are designed into the module. The performance issues considered include thermal properties, photovoltaic potential, life-cycle costs, environmental impact, sound (cancellation, projection and deadening), light (projection, transmission and control) atmospheric, articulation and biomorphic potential.[24] Each is accountable at the modular level.

Experiment #2: Design, Simulation and Modularity—The Endoskeletal Model

In Experiment 2 (Figure 4), an Endoskeletal assemblage of irregular modules is constructed from components of known quantity and type; the design parameters of the base module include scale, location, repetition and orientation. Design evolves through the combined interaction of the designer and the machine, engaging rules one, two and three of the Design Threshold. Each module inherits the self-similar design characteristics of its prototypical parent.

Fig. 4. Endoskeletal Model Simulation

Unit modularity is derived from the 1x1x1 standardized modular block. The designer interactively establishes the location, scale and orientation of each module. Similar in concept to Experiment 1, a complete engineering solution is inherent at the modular level, although with separate but complimentary considerations of structure and membrane. This process imposes an orthogonal filter; free form warping and bending are not allowed. Since modular variations are consistent with the unit module, the fabrication process is similarly accessed and controlled at the modular level.

Matrix, Experiments I & II

In summary, differentiation from the previous matrix (Figure 5) is achieved primarily in terms of process since the intelligent machine is now the co-determinant of form.

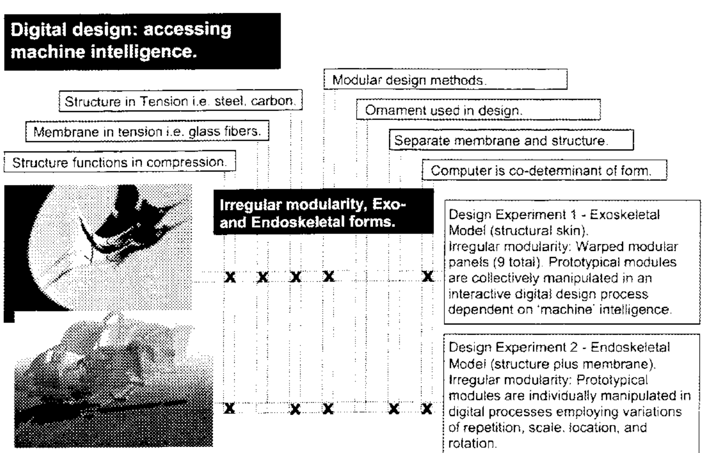

Fig. 5. Digital Membrane-Structure Matrix

The systemic nature of the computer model creates an opportunity for the entire design process to be interactively re-engaged – the concept of architecture as frozen music is no longer compelling, at least in the design process.[25] In both experiments, similarities in the application of design principles are germane. Because the pre-determination of means and method in design and simulation avoids the issue of build-ability, the means are inherent in the process. Finally, the Exoskeletal and Endoskeletal forms employ the module as a fundamental means to understand both design and construction.

In both previous experiments, a systemic DNA-like sequence of unbroken design decisions, modeled as reference objects, allows the substitution and alteration of the design module at any point in the design chain. It is the ability to keep the design process 'alive' in an unbroken, editable event of design decisions, along with the interaction of machine and human intelligence, that most accurately explains the potential suggested in both approaches.

OPERATING AT THE MODULAR LEVEL

Speculation concerning the unrealized potential of skin in modular design was examined in the classroom; two primary configurations were identified. In the first, the membrane is monolithic, through the composite layering of function, i.e. transparency plus thermal properties plus strength. In the second, assemblages of components function as an environmental engine. The classroom also a range of unrealized functional considerations of skin at the modular level: Environmental noise pollution (street, airport etc.) could be filtered or eliminated through noise cancellation technologies; inversely, sound (message media) would be projected through the technology of transducers and sound pressure generators. Semi-permeable membranes could control atmospheric filtering; Gore-Tex like materials would permit vapor transmission but not water transmission. Sensory skins of olfactory capability could selectively filter, i.e. allow the smell of a rainstorm, but remove hazards of pollution. Illumination skins would generate light, broadcast messages and project visual content. In a futuristic vision, organic skins would incorporate generative and regenerative capabilities in an organic system; it would convert, store, filter and purify the environment—a machine of nature.

CONCLUSION: IN SEARCH OF THE PERFECT SKIN

Butchered animals' skins are a brutal remnant of our ancestral heritage and an ever-present reminder of our need to control, alter, contain, filter and shelter through the use/reuse of membrane and structure. Despite vast technological advances, the principles involved are constant: the modification of the environment based on the perception of the senses. It is the relationship of membrane (skin) to structure that is under constant revision.

Of the identifiable markers within the evolutionary milieu of membrane and structure, none was more deterministic or influential than the events surrounding the Industrial Revolution. While the evolution of stone is traceable to events preceding the Pyramids, spanning the birth and death of great civilizations, its lineage ends where science and technology intervene.

Unquestionably the digital revolution has visited vast changes upon contemporary social, political and economic order, but it now appears that the digital revolution is a subset of the Industrial Revolution—the intellectual phase in the specialization of science and technology. At present, except for design management, digital technology has exhibited little propensity to radically change the status quo in architecture. It has, however, extended the linear logic of the Industrial Revolution through the etching of circuits on silicon chips. That is the point where this study and the accompanying experiments intervene; together, they are an attempt to remediate the disruption that technological advances have imposed on environmental design. The CAD model is a document in need of translation, and herein lies the problem. In summary, Computer Aided Design when implemented as a visual gesture, even as a carefully constructed and observable model, is essentially a foreign object in the language of construction.

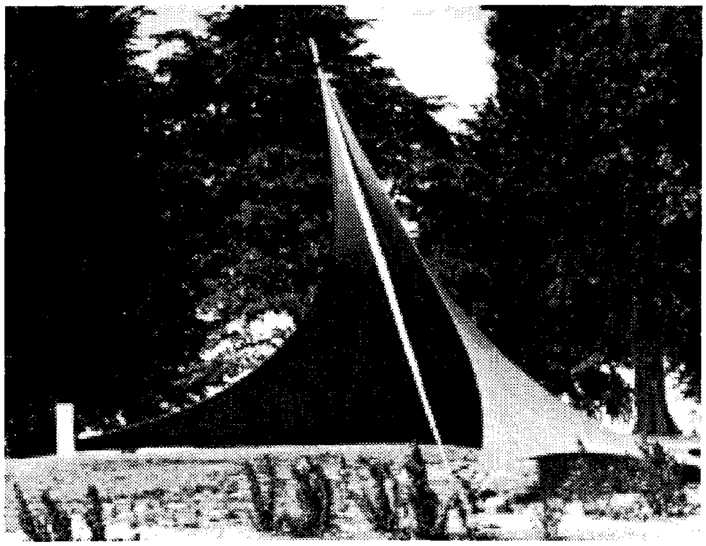

Fig. 6. Frei Otto, Prototype (1955).

While the separation of membrane and structure is readily documented in the historic record, i.e. Frei Otto's novelty cable-stayed tent structures (Figure 6), SOM's Sears Tower and Frank O. Gehry's titanium-skinned Guggenheim Museum, it is more difficult to document the radical restructuring in the social, political and religious ordering that accompanied this technological and spiritual realignment. However, the consecration ceremony offers a telling glimpse into the perceived realignment of function.

A cold steel frame supported the new Woolworth Building's skin of stone and glass. "Doctor Cadman, the noted divine, has called this Building, 'The Cathedral of Commerce'."[26] In 1913 President Wilson pressed a tiny button and dedicated the regal edifice, "(It was)... the most beautiful building in all the world erected to commerce." At the dedication, 80,000 brilliant lights venerated commerce—not God—its consecration was not to repel the devil, but to shine as a beacon to commerce. The seamless spiritual device of salvation, the consecrated cathedral, had undergone a secular transformation into a Cathedral to Capitalism. "(A) magnificent splendor, a masterpiece of art and architecture, a Glorious Whole, quite beyond the control of human imagination." [27]

Inevitably the proximity of current events distorts one's perspective on the present. It is impossible to conclude with certainty that with we are experiencing an expansion of the logic of the Industrial Revolution, the 'High Industrial Era' of machine intelligence; however, it appears increasingly likely. It is also becoming apparent that the issues of visual obsession and sensory denial are evolutionary complications in the natural course of the "'old" revolution, imbalances between *Aesthetic Desire and Material Fact* in need of remediation.

NOTES

[1]Jeremy Podeswa, *The Five Senses* (Canada: Independent film, 1999). The film considers the vagaries of perception in a world filtered through each of the five senses. Robert, the gay cleaning man perceived, "I can smell love." I have expanded that thought.

[2]For clarity, the term skin uniformly addresses the skins of buildings in the context of 'that critical zone where the fundamental character of architecture, both in terms of performance and visual quality, often resides', unless otherwise noted.

[3]Ray Kurzwell, *The Age of Spiritual Machines* (NY: Viking Press, 1999). p. 70. It turned out that the computational problems that we thought were difficult i.e. playing chess were difficult, were not; "What proved illusive were the skills that any five-year-old child possesses: telling the difference between a dog and a cat ..."

[4]Kenneth Frampton, *Studies in Tectonic Culture* (Cambridge, MA: MIT Press, 1995). See page 5.

[5]Francis D. Klingender, *Art and the Industrial Revolution* (Plaistow, England: Curwen Press, 1947). Timber while structurally suitable, was an unacceptable fire hazard, with a crisis in supply in the 1700's.

[6]Fredric Turner, *Rebirth of Value - Meditations on Beauty. Ecology, Religion, and Education* (Albany, NY: State University of New York Press, 1991). The Medieval Cathedral was the terminal expression of a 'working' spiritual device in western culture. In spiritual terms, its mission was immensely more sophisticated (universal salvation) than the spiritual capability of the pyramid. Nevertheless, there was a radically reconfiguration and a diminished perception of the role of spiritual mechanics. Turner, the poet, notes that scientific principles, thermodynamics in particular, either as invention or understanding, signaled this transition.

[7]Catholic Encyclopedia, *Sacrifice*, http://www.newadvent.org/cathen/13309a.htm (First web publication, 1997). *By sacrifice in the real sense is universally understood the offering of a sense-perceptible gift to the Deity as an outward manifestation of our veneration for Him and with the object of attaining communion with Him. Strictly speaking however, this offering does not become a sacrifice until a real change has been effected in the visible gift (e. g. by slaying it, shedding its blood, burning it, or pouring it out.)*

[8]Catholic Encyclopedia, *Twenty-second chapter, Acts of the Apostles (v. 16)* (First web publication, 1997).

[9]Georges Duby, *Medieval Art, Europe of the Cathedrals 1140 – 1280*, (Geneva: Booking International, 1995) p. 26. *The function of the stain-glass window is to admit thew light of day and in doing so to transmute it, embellish it, invest it with the hues of the various gems – rubies, topazes, emeralds, lapis lazuli – which according to the ancients were endowed with magical virtues corresponding to specific properties of the soul.-Duby*

[10]Catholic Encyclopedia, St. Augustine of Hippo (354-430), The City of God, Chapter 19, *www.newadvent.org/fathers/120111.htm.* He commanded those luminaries of heaven that are obvious to our senses to divide between the light and the darkness. "Let there be," He says, "lights in the firmament of the heaven, to divide the day from the night;" and shortly after He says, "And God made two great lights; the greater light to rule the day, and the lesser light to rule the night: the stars also. And God set them in the firmament of the heaven, to give light upon the earth, and to rule over the day and over the night, and to divide the light from the darkness."

[11]Catholic Encyclopedia, *www.newadvent.org/cathen/05584a.htm.* Refers to the union with Christ by love. The first and principal effect of the Holy Eucharist is union with Christ by love (Decr. pro Armenis: adunatio ad Christum), which union as such does not consist in the sacramental reception of the Host, but in the spiritual and mystical union with Jesus by the theological virtue of love. Christ Himself designated the idea of Communion as a union love: "He that eateth my flesh, and drinketh blood, abideth in me, and I in him" (John, vi, 57). St. Cyril of Alexandria (Hom. in Joan., IV, xvii) beautifully represents this mystical union as the fusion of our being into that of the God-man, as "when melted wax is fused with other wax".

[12]Catholic Encyclopedia, *Consecration*, *www.newadvent.org/cathen/04276a.htm* (First web publication, 1997).

[13]Random House, Electronic Dictionary, 1991. "In Kantian terms, a thing as it appears to and is constructed by the mind, as distinguished from a noumenon, or thing-in-itself."

[14]Norman L. Geisler and Ralph E. MacKenzie, *The Catholic-Protestant Debate on Papal Infallibility*, Christian Research Institute. STATEMENT DC170-4 What Think Ye of Rome? (Part Four): *www.equip.org/free/DC170-4.htm.*

[15]S. Parkes Cadman, The Cathedral of Commerce - Woolworth Building, New York (New York: Thomsen – Ellis Company, 1917). Forward by Camden.

[16]Frederik Turner, Rebirth of Value - Meditations on Beauty, Ecology, Religion, and Education, (Albany, NY: State University of New York Press, 1991).

[17]Neil Leach, The Anaesthetics of Architecture, (Cambridge/London: MIT Press, 1999) p. 44

[18]Ibid., p. 45.

[19]Robert H. Flanagan, "The Design Threshold" (Proceedings, II Seminario Iberoamericano de Grafica Digital, vol. 2, 1998). pp 38-43.

[20]Robert H. Flanagan, "Designing by Simulation" (Proceedings, III Seminario Iberoamericano de Grafica Digital, vol. 3, 1999). pp 25-30. Modified matrix first published here.

[21]William J. Mitchell, *e-topia, Urban Life, Jim - But Not As We Know It* (Cambridge/London: MIT Press, 1999). In his discussion of 'Machines for Living In' (p.63-4), Mitchell's question "How smart, does a washing machine need to be?" He posits, "Maybe it should learn when you want fresh laundry ready". Presently, the designer engages the linear logic embedded of the machine. Nevertheless, the computer itself is of a very primitive state of machine intelligence.

[22]Digital techniques have yet to find recognizable expression in architecture.

[23]Discreet Software, 3DStudio MAX v. 3, FFD modifier.

[24]Cultivate the oyster, not the pearl; the creation of DNA engineered organisms seems probable in the not too distant future – the ability to create and modify architectural organisms will significantly extend Charles Darwin's 1859 understanding in *Origin of Species.*

[25]The philosopher Goethe's 1829 reference to architecture as 'frozen music'.

[26]Edwin A. Cochran, The Cathedral of Commerce - Woolworth Building, New York (New York: Thomsen – Ellis Company, 1917). Introduction.

[27]Ibid., Introduction.