A Bioclimatic Approach to Integrated Design

Form, Technology, and Architectural Knowledge

by

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May, 1989

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARCHITECTURE
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
JANUARY 1996

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"I know of nothing more pleasant, or more instructive, than to compare experience with expectation, or to register from time to time the difference between idea and reality.

It is by this kind of observation that we grow daily less liable to be disappointed."

Samuel Johnson

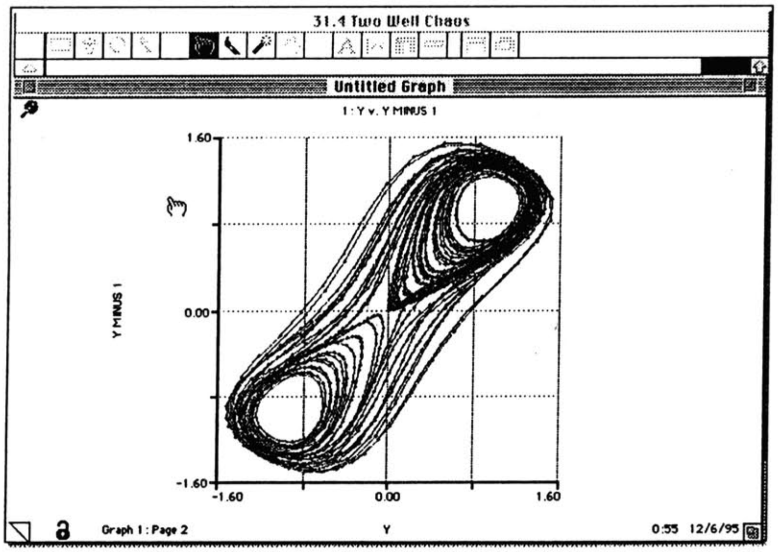

Fig. 1 Phase plot of two-well chaos simulation

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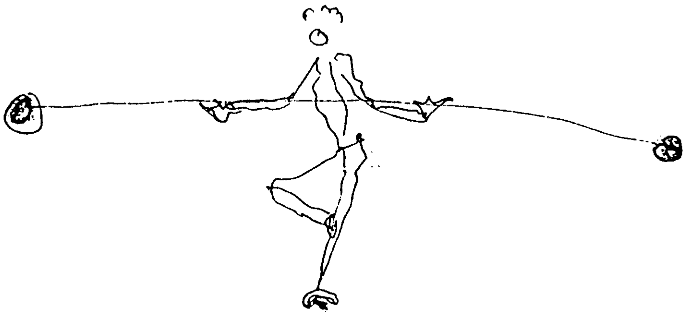
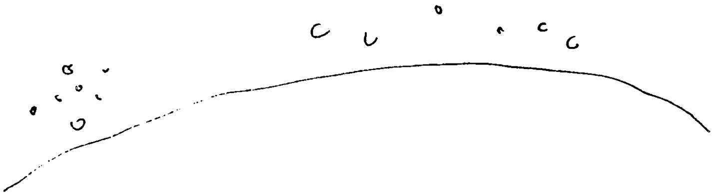




Our traveling globe in galactic endlessness is divided into latitude and longitude.

With help of this grid, every point on the earth's surface has its number.

At the grid's intersections each receives nourishment, each creature receives its individual technology, its structure formed and created by the clouds' movements, the wind's strength, and the shifting positions of the sun.

On this organic mat, the acrobat (builder) attempts, with the help of instruments, to deceive gravity and challenge death with every leap.

And when the perplexities of thought within your soul should create space on earth, arises a duel with substance. Midst brutality's heat, beauty is born...

SVERRE FEHN

A Bioclimatic Approach to Integrated Design

Form, Technology, and Architectural Knowledge

by Matthew J. O'Connell

Submitted to the Department of Architecture on January 19, 1996 in partial fulfillment of the requirements for the degree of Master of Architecture

ABSTRACT

This thesis explores a holistic design process through which architectural elements can engage the dynamic forces of natural phenomena and integrate the spatial and temporal experience of building form with its physical environment.

The framework for this exploration is a contextual mapping of dynamical systems and complexity theory to the processes of architectural design. By incorporating concepts and methods from the study of non-linear dynamics, a broad base of scientific knowledge aimed at understanding physical behavior in nature, this thesis proposes a synthetic relationship between architectural elements, their physical performance in the context of natural phenomena, and their contribution to a coherent spatial structure.

Modern technological imperatives have rephrased the sensible relationships between architecture, climate, and inhabited space as a problem for "environmental controls". The contemporary urban office building, under economic pretenses, exhibits a particular over-dependence on external machinery for light, ventilation, and thermal comfort, often to the detriment of physical experience.

This thesis emphasizes the use of scientific knowledge and computational tools in the early processes of design in an attempt to investigate the manifestations of physical energy -- light, air, and heat --in the building's final form. By addressing these physical performance criteria as spatial influences during preliminary design, this thesis supports an integrated framework for professional collaboration and examines a cultural context for the application of architectural knowledge.

A bioclimatic approach to design, therefore, is a synthetic response to the dialectic between the tectonics of physical experience and the dynamics of the natural environment.

Thesis Supervisor:	Andrew Scott, RIBA
Title:	Associate Professor of Architecture

Preface

This Thesis emphasizes the development of a practical and theoretical context for a bioclimatic approach to architectural design. As in any directed inquiry, it is an effort to characterize the dimensions of future investigations which might be pursued in a professional environment.

Recognizing the limits of an academic exercise, practiced in isolation from the kinds of collaboration and interaction found in many other design settings, this document is intended to stake out the dimensions of the design process. Many of the issues which deserve more careful investigation, and which could substantiate an integrated philosophy, were simply not possible for one individual to undertake in the limited amount of time allocated to this Thesis.

The Case Study Design is intended to phrase specific questions and explore their answers through the medium of architectural form. It should be noted that the site chosen for the design has seen an almost continous series of proposals for renewal and reuse over the last twenty years. This Study should be understood, therefore, as a conceptual proposal, borrowing on the specific qualities -- physical, cultural, and environmental -- which the site has to offer.

At a critical point in the process, it was decided to emphasize the potential of a exploring a strongly vertical building. While this diverges with the sensible capacity of this particular site, and quite likely with its zoning regulations, this decision reflects the freedom of an academic exercise. In the end, this direction to the experiment was more effective in clarifying those architectural principles which might characterize a bioclimatic approach to commercial building design.

I would like to acknowledge and thank my Advisor, Professor Andrew Scott, for his ongoing support and sensitive direction during the preparation of this Thesis. If there exists a modicum of clarity in the Case Study Design, much of its purposefulness has derived from our conversations, which always emphasized the potential, rather than the limitations, of form-making and the architectural design process.

I trust our paths will continue to evolve -- and perhaps converge again -- in our search for quality at the intersections of architecture and the environment. Your friendship is the greatest dividend of our work.

In addition, I would like to recognize the members of my Thesis Committee, Professor Akos Moravanszky, and Professor Ken Kao. To each I extend my gratitude for their patience and support as ideas and concepts slowly converged into architecture. You will always hold my great respect as a teachers, scholars, and active contribuors to your specific areas of practice.

Inevitably this process has revealed more questions than firm answers, yet as a result of this preliminary research, it is possible that such questions might now be more clearly phrased, and serve to direct future research .

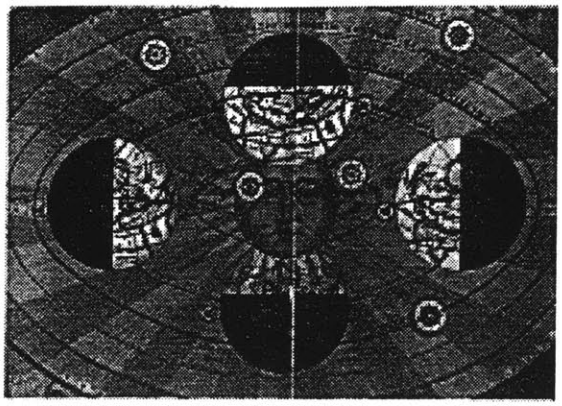


Fig. 2 The Copernican System

Introduction

Architecture and the Realm of Science:

Symbol, Function, and Technology in Modern Design

The assumption that architecture can derive its meaning from functionalism has marked the evolution of Western architecture in the past two centuries [1]. As a result of this influence, specific knowledge about a building which can be understood through the laws of science has taken precedence over the more ambiguous dimensions of reality, embodied in Husserl's *Lebenswel* —the world as lived — which are often accessible only through the realm of "poetics" [2]. Therefore, the communication of a truly relevant frame of reference, one which connects body and space through experience, is often obscured behind formal justifications for an architecture of efficiency and economy.

Prior to the nineteenth century, architectural intentions were necessarily symbolic, and form was associated with metaphor. Such constructs were a means of reconciliation between the *logos* and the *mythos* [3], the finite and the eternal, expressed in a proposal for

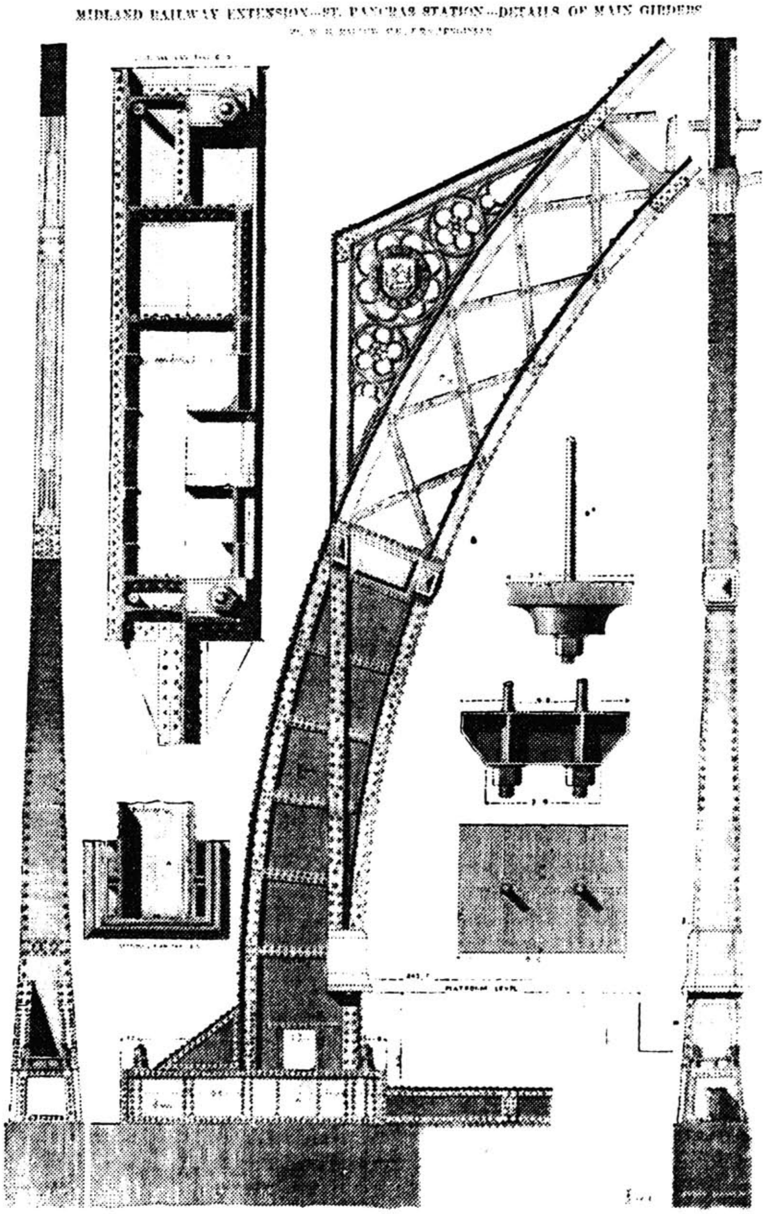


Fig. 3 *St. Pancras Station, Iron Details*

building. Various incarnations of this dialectic have been reiterated throughout the modern architectural movement, notable among them the short-lived tenure of Johannes Itten in the Bauhaus (1919 - 1922). His replacement by Laszlo Moholy-Nagy shifted the school's focus from creative, almost spiritual explorations of art and architecture to the functional integration of craft design and industrial production. The consequent authority asserted upon the "objective" gave increased meaning to the derivation of form from the productive method, material constraints, and programmatic necessity [4].

The genesis of form is arguably the most contentious problem in architectural design. Increases in the transfer of technological knowledge from science and engineering into products for building construction [5] has reinforced a positivistic approach to the morphology of individual components and entire building assemblies.

Among the consequences of the rule of reason is the illusion of control over the human environment, and a corresponding loss of a sense of mystery once nurtured through mythology. Having forgotten about fragility and a capacity for wonder, our culture thrives on the assumption that all phenomena, from elements of nature to aspects of human behavior, can be explained with scientific theories [6].

Architecture has yet to recover its place in popular culture as a profound form of knowledge in its own subjective entirety, rather than merely an aggregation of physical sub-systems and elements. The failure of a functionalist approach to design can be traced to the invariance demanded by a reductive process based on mathematics, a process which lacks the transient ambiguity of time and the registration of human form.

LeCorbusier once described "Architecture", as the "masterly, correct, and magnificent play of masses brought together in light. Our eyes are made to see forms in light." [7] This poetic appeal begins to engage the dynamic quality of space occupied by a phenomenon of nature, yet remains consistent with Boullee's views on the certainty between the causes and effects of perceptions in space [8]. The legacy of Modern form-making can be interpreted as a visual coda based on image values often wholly separated from the experience of a particular building. By identifying it with a static visual condition, the appropriation of Bauhaus ideals under the guise of a "style" has, intentionally or not, undermined whatever potential for reconciling *mythos* and *logos* the "machine for living" may have once possessed.

The current state of introspection regarding this planet's physical resources is a reminder of a significant uncertainty regarding the sustainability of our exploitative society. Paradoxically, the awareness of our own condition has been generated by the very same advancements in knowledge and technology which threaten our collective resources.

While Western thought appears to be floundering in its arrays of excessively formal systems, the meaning and consequences of these complex syntaxes are being expressed as physical realities — including pollution, resource shortages, and price increases — which can be understood through natural ecosystems [9]. How to design, or dwell, with knowledge of such an untenable course ? The extension of this self-awareness into architecture has not surprisingly shown characteristics of a functional approach subsumed by technology.

The relationship between a building's physical performance and its spatial experience can be most crudely framed by using energy consumption as a signifier for the complex flows and interactions which the building experiences during any particular period of time. As a commercial exchange, the ebb and flow of people and the energy requirements for a

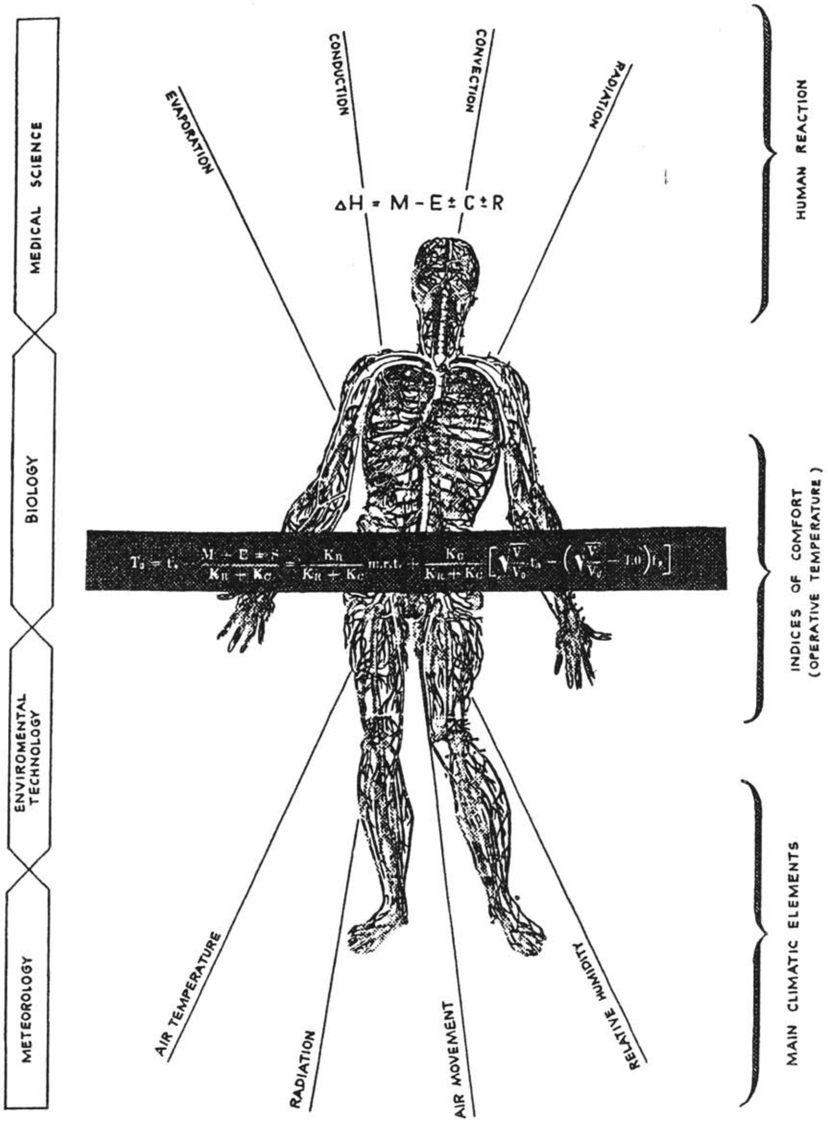


Fig. 4 Biometrics

buidling's inhabitation can be brought into a dialogue which recognizes the symbiosis between empirical functionalism and a phenomenological experience, albeit weighted towards its financial value.

Although such an approach risks marginalizing a more poetic approach to spatial constructs, there exists in an open dialogue an opportunity to re-establish the connections between performance and experience, regardless of which path might prove the most elegant means of achieving this link.

Current efforts to mitigate the unbounded consumption of natural resources through conservation and the use of renewable energy sources have evolved as a direct consequence of the "crisis" of fuel availability over two decades ago. The sense of immediacy brought by day to day shortages has passed, thanks in part to the political control of significant fuel reserves, but the architectural implications for building design which began in that recent era have taken strong roots and caused a re-assessment of the strategies and technologies necessary for dwelling with the natural environment rather than against it [10].

Despite the progressive demeanor which the architectural profession attempts to project, strategies for low-energy design can be exceedingly difficult to bring from concept to production. Typical preliminary

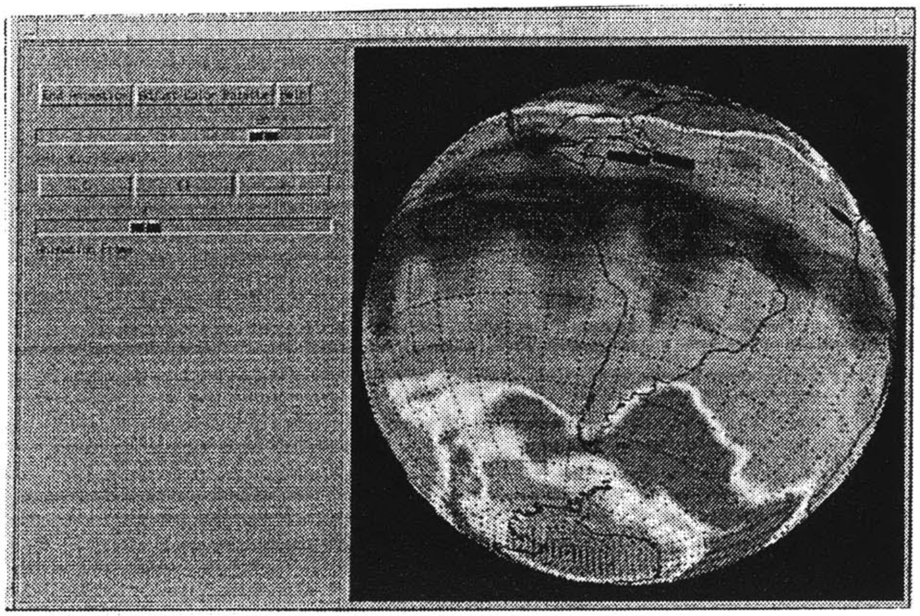


Fig. 5 Computer Visualization of the Earth's Ozone Depletion

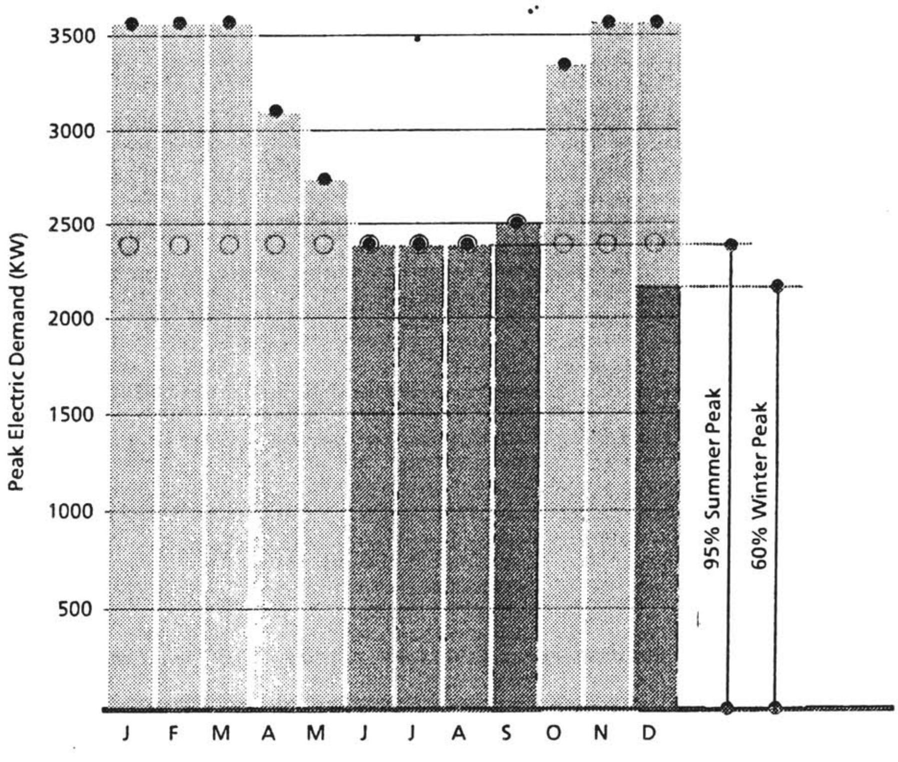


Fig. 6 Peak Electric Demand based on Summer Rates

design approaches deal with the necessities of energy-intensive mechanical systems in far more detail than the fundamentals of passive or hybrid climatic systems.

The logistics of generating a "comfort zone" on the interior of a building remains an exercise independent from the true dynamics interactions of light, heat, and air in the outdoor environment. By satisfying "set-" and "balance-points" with increases in auxiliary power, in the form of heating, cooling, or often both simultaneously, the comprehensive effect is to reinforce the boundary between indoors and out.

Not without coincidence, the thrust of research and development in low-energy design involves the application of dynamic building envelope systems to the boundary layers of an occupied space. Although technologically sophisticated and beautifully detailed, this approach risks to further polarize the dialogue between the experiential quality of a room or building and the specifications for its physical performance at the level of the sub-system. In terms of the *mathemata*, this disparity is driven in part by the exclusive insistence on low-energy results, a reductive agenda with invariant criteria.

The power of the brief, the onset of an architectural idea, is its influence on perception and the implica-

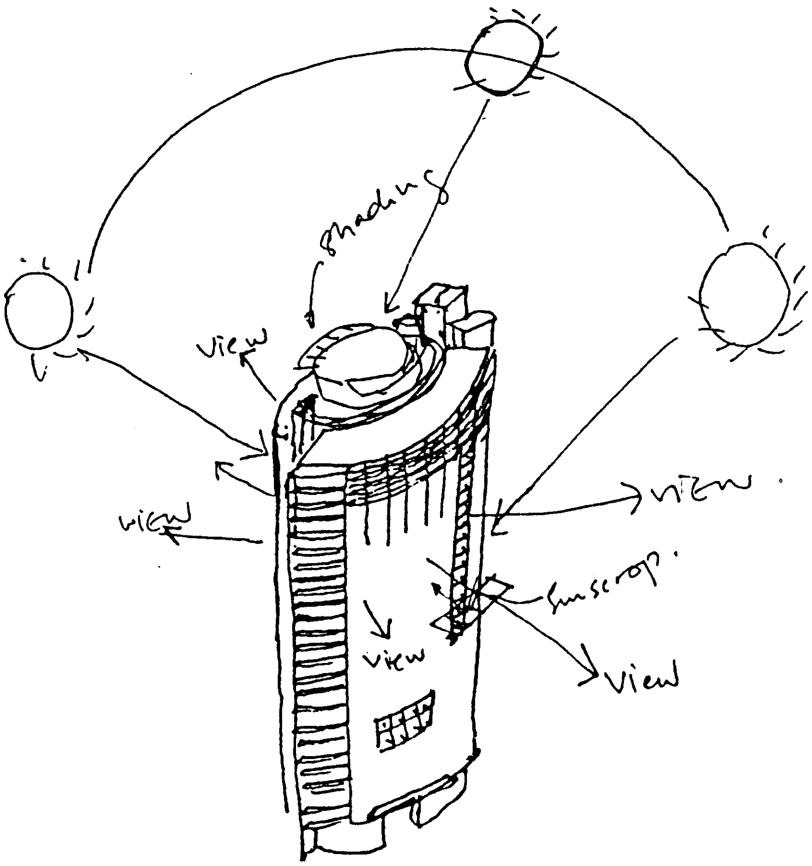


Fig. 7 Ken Yeang, China Tower 1, Sketch

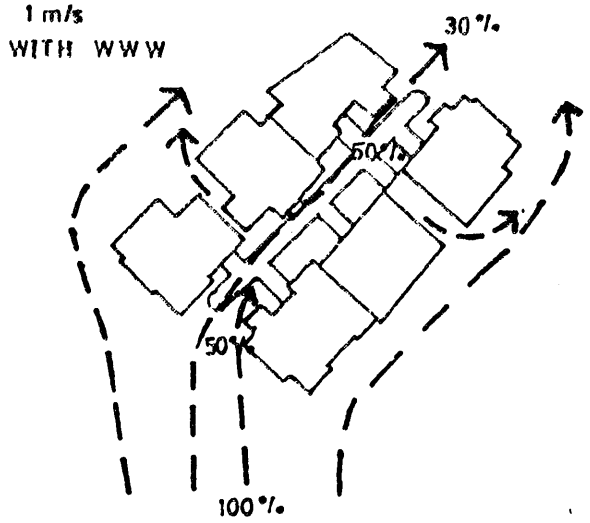


Fig. 8 Ken Yeang, Penggiran Apartments # 1, Airflow Sketch

tions for specific architectural explorations. Among the qualities of historically sound design is a reciprocity between multiple scales of the building's intentions and eventual actions. As such, the detail evokes some quality which is germane to the site as a whole, for example, or the movement organized through a series of spaces manages to establish an association with some relevant condition in the region.

So, the layering approach developed to support technological innovations at the scale of the enclosure could also serve as a metaphor for interaction with a mesoclimate, leading to strategies for openness, permeability, and interaction at a holistic level as well as in detailed, localized phenomena.

This type of bioclimatic approach has been exhuberantly tested through the global continuity of vernacular expression, and selectively transformed over time by means of associative derivations of form, materials, and spatial experience. This is notably evident in the work of Alvar Aalto [11] and more recently Ken Yeang [12], each of whom generated a heuristic understanding of localized interplays between climate and form, although half a century apart, and produced a body of architecture which integrates specific qualities of light, in the case of Aalto, and the interplay of multiple natural phenomena in the work of Yeang.

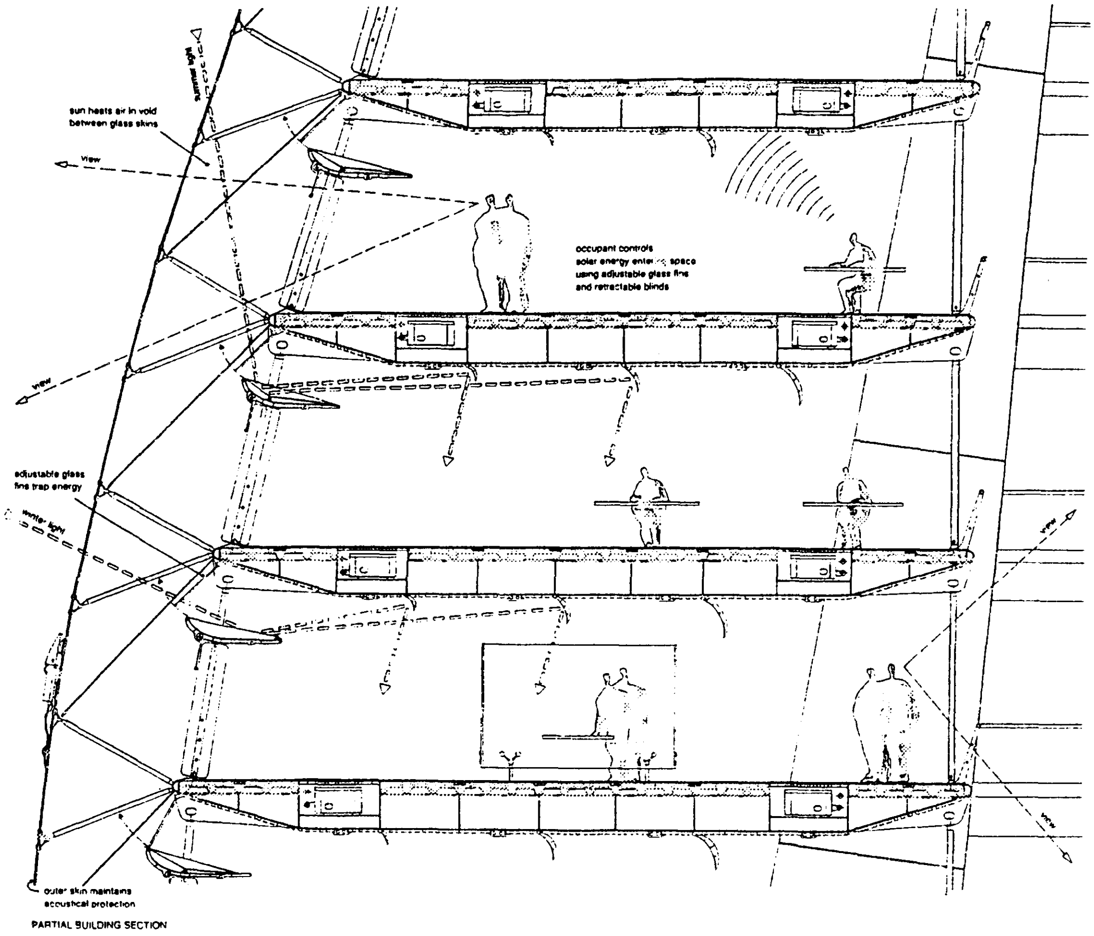


Fig. 9 Future Systems, Green Building, Section Study

A fundamental address of the environmental opportunities and their ecological effects separates the architecture of Ken Yeang from the lexicon of Modern design. The importance of an integrated approach to site and detail is infused in his projects from their conception to their gradual inhabitation by clientele, plant life, and the forces of nature [13]. This vision of an open and permeable framework for the interaction between climate and occupant recalls Future System's Green Building project [14], devised as an alternative to the conventional urban office block. Developed in collaboration with Ove Arup & Partners, the Green Building was an attempt to derive a physical form from the conceptual premise of an environmental filter which met with standardized programmatic criteria for office use.

The technical feasibility of a proposition such as the Green Building is well within today's capacity, benefitting from recent developments in building envelope systems as well as efficient lighting strategies. However, few buildings since have taken the concept in its largest sense as far as Yeang and his senior contemporary Michael Hopkins [15].

While Rogers[16], Foster[17], Grimshaw[18], and to a lesser extent Piano and Herzog[19], have led the

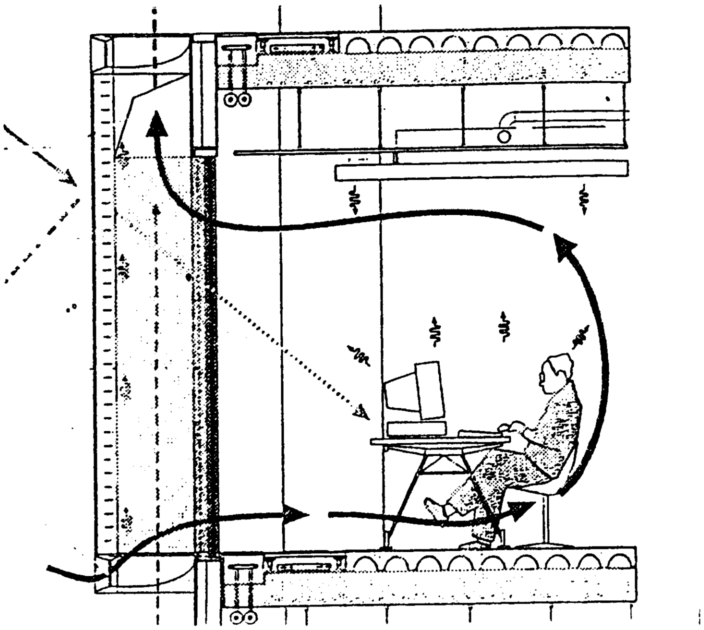


Fig. 10 Norman Foster, ARAG Headquarters Sectional Study

assault on the application of sophisticated technology to the problem of low-energy design, Yeang's skyscrapers and Hopkins' recent offices completed for the Inland Revenue centre [20] clearly approach a comprehensive understanding of the dialogue between climate, building form, physical performance, and spatial experience. Foster's proposal for a passively ventilated and naturally daylit office tower in Frankfurt, Germany [21], should place his practice among those which are beginning to fulfill the conceptual potential of the Green Building.

By clarifying the teleological differences between a " system boundary " approach to low-energy buildings and a "holistic" and spatially driven strategy for bioclimatic design, there exists the potential for understanding how one might approach a reintegration of the physical forces in nature — gravity, light, air, heat, sound — with the phenomenological dimensions of direct communication and sensory interactions, enabling us to extend the geometry of experience into architecture [22]. Further, this approach engages the design team on a directed journey which acknowledges the power and influence of a quantitatively informed process without divesting of the metaphorical potential and associative quality of a sophisticated architectural proposal.

"Morphology is not only the study of material things, and the forms of material things, but the dynamical aspects, in terms of force, of the operation of energy."

-- *D'Arcy Thompson*
On Growth and Form

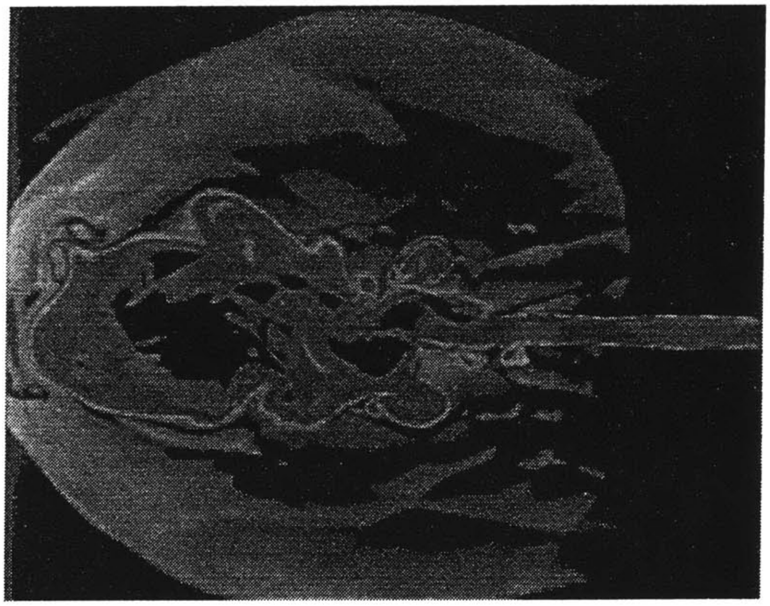


Fig. 11 Turbulence Simulation using Non-Linear Algorithms

Design Process

Like many applied arts and sciences, the practice of architecture which results in built form relies on an appreciation of its context at many levels. To develop a design proposal so that it may become “architecture” requires knowledge of aesthetics, siting, function, structures, mechanical systems, graphic conventions, and perhaps, according to Vitruvius, even a “theory of the heavens”.

The artifacts of practice, the buildings themselves, are socially and physically constructed by an array of individuals. However, these individuals inevitably fall subject to the influence of larger cultural forces which, if poorly understood, can undermine the final artifact in a number of ways. While the contributions of creative designers are necessary for the production of a successful building, they are by no means sufficient.

This Thesis investigates a particular congruence of formal, technical, and philosophical issues under the label of “integrated design”. This term deserves clarification, as do the constituent elements themselves.

The primary focus of this Thesis is to examine how building form and spatial organization can respond to criteria for environmental performance. The hypothesis is that these two realms — architecture and natural phenomena — can be mutually supportive. By creating an artifact whose physical behavior and

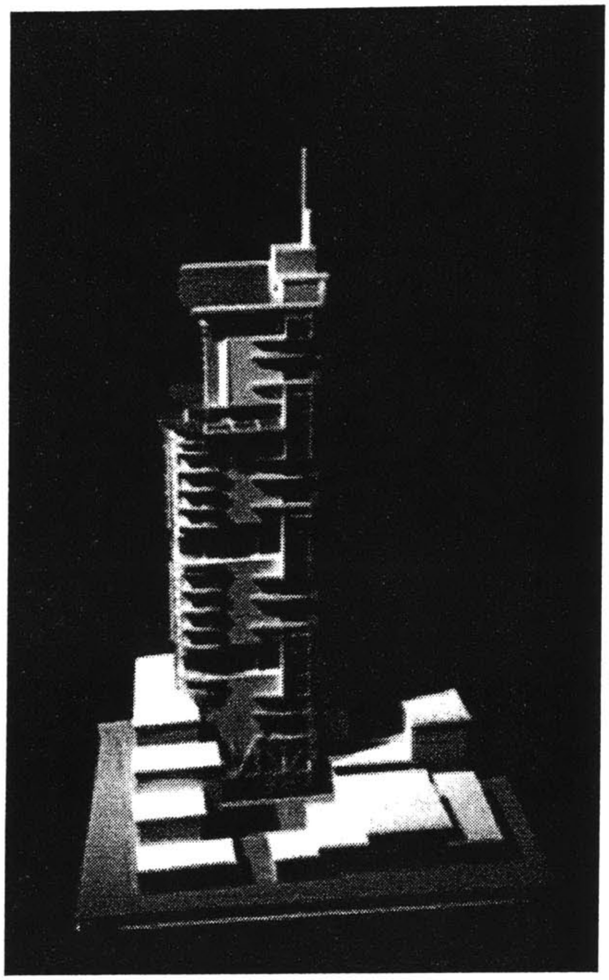


Fig. 12 View of Study Model from South

symbolic presence are shaped by environmental responses, a building can foster in its inhabitants an appreciation for their role amidst complexities of the world around them.

Such a building may at least invoke a sense of wonder, and possibly inspire a sense of responsibility for the quality of our natural environment concomitant to the privilege entrusted to *homo fabricans*, creators of the built environment.

The experience of space through the movement of light and air, temporal changes in thermal sensation suited to specific environments, and the opportunity for users to control their immediate climate have each informed the evolution of the Case Study Design presented in following chapters.

The degree to which this Design can be judged "integrated" is therefore related to its capacity, as a preliminary proposal, to be thoughtfully inhabited through the experience of time, to harness and direct the power of natural phenomena, and to reflect these values as a symbolic entity in the surrounding cityscape.

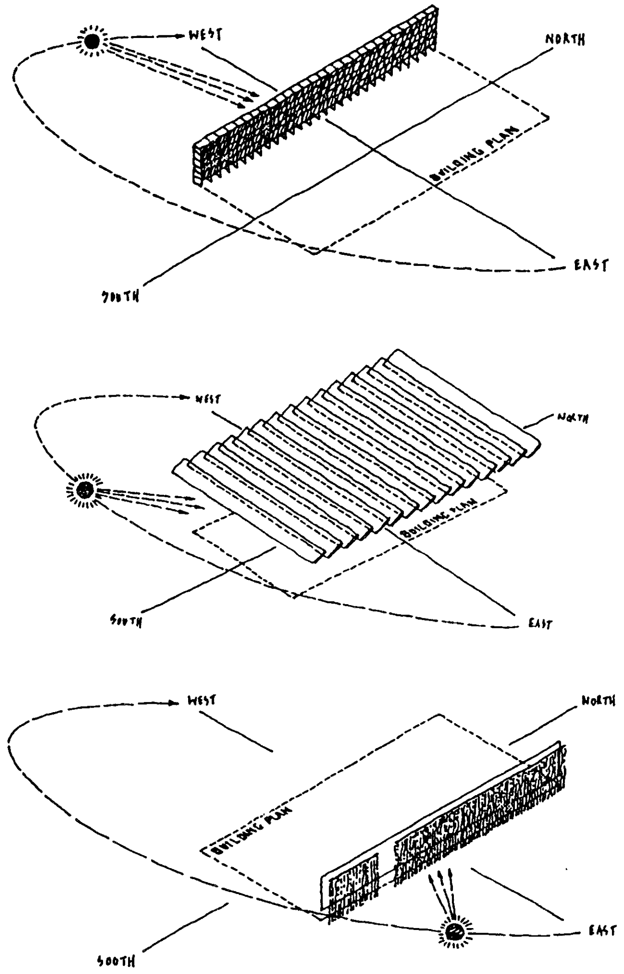


Fig. 13 Nicholas Grimshaw, Seville Pavillion, Solar Axis

Integrated Design

Towards an Architecture of Elements

The development of an environmentally integrated design proposal involves the consideration of multiple physical phenomena and their interaction with architectural elements. The behavior of these elements can be characterized by the scale at which they respond to environmental forces and the system boundary associated with this effect.

While any design can be holistically understood as a series of embedded layers, each dependent on another for function and form, the building envelope bears a primary role in communicating an exterior physical presence and suggesting (or perhaps veiling) the interior spatial functions. Whether tacit or highly expressed, the interior spaces rely explicitly on the building envelope for their mediation with the outdoor environment.

In the last half of this century, commercial buildings have come to rely almost exclusively on the application of technology, in the form of external machinery, for the thermal comfort of their inhabitants. This artificial separation between inside and outside came about, in part, through the propagation of deep-plan spaces, made possible by artificial lighting, resulting in a further distancing from the influence of natural phenomena.

One consequence of this unseemly evolution is a current acceptance of the high energy intensity required for commercial office space. This condition is so entrenched in our design culture that many central mechanical plants, beyond simply being accepted as a viable solution, are often oversized by a factor of 1.5 to 2.0, resulting in further demand without significant improvements in the quality, or the temperature, of the working environment.

This canonized approach to personal comfort suffers several shortcomings. First, as a design process, it responds to a limited set of criteria for engineering performance. The resulting "optimization" of a closed mechanical system undermines the possibility of engaging localized phenomena — strategies for solar gain, natural ventilation, and thermal mass — while eliminating the involvement of the occupants in their personal comfort.

Second, the current approach does not include any built-in measures for efficiency, be they in scale or in performance. More significant than the cost of the energy itself, including the larger ecological effects of generating this energy, is the loss of working productivity related to poorly designed environments.

This point should be reinforced, as it qualifies the importance of the design context in the broadest sense. Current architectural practice holds an almost wholly ignorant view of those aspects of economic viability which, ironically, could instead define the added value of a design project, thereby supporting those formal innovations which architects relinquish in the purgatory of detailing and construction processes.

Recent case studies of the links between environmental quality and occupant productivity are outlined in later chapters, yet the paucity of knowledge regarding the economic implications of specific design proposals heralds the importance of clearly defining an intended system boundary — both physical and and cultural — within which the negotiated art of design can take place. This boundary can help clarify and define the working principles which guide interactions at different scales, but at the very least the boundary can serve as a measure of effectiveness of design strategies within its limits before addressing the larger context.

Returning to the building envelope as a study in system boundaries, what follows is an assessment of recent design initiatives which attempt to develop the relationship between inside and outside with architectural form.

The examples chosen characterize five layers of tectonic integration between natural phenomena and architectural form. These layers reflect an increasing degree of commitment to a holistic design agenda, and are also useful in understanding, evaluating, and predicting physical perfomance criteria.

For example, traditional scientific methods assert that system boundaries are defined by areas exhibiting no energy interaction beyond their limits. As adiabatic elements, therefore, performance within these boundaries can inform what role technology can play in the design and construction process.

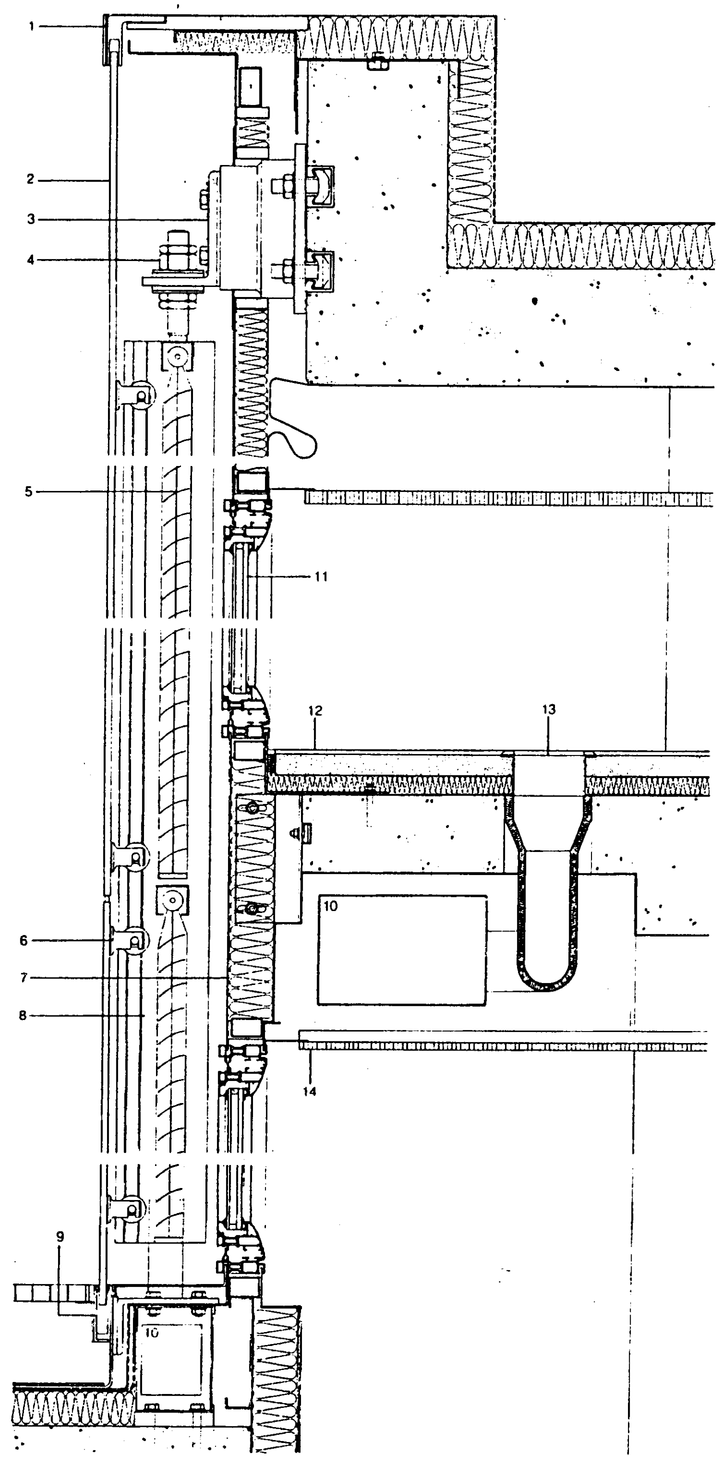


Fig. 14 Norman Foster, Duisberg Business Centre, Envelope Detail

Design Research: Innovative Envelope Systems

For the purpose of this study, the layers are discretized based on the building envelope element's areas of influence, represented by an emphasis on:

1. Materials and Molecular Behavior

2. Surfaces and Boundary Conditions

3. External Elements and Peripheral Conditions

4. Sectional Assemblies and Construction Sequence

5. Spatial Organization and Tectonic Legibility

The latter categories are shown to lead more directly to solutions whose performance criteria are best integrated with sensible qualities of space, such as improved daylight and comprehensive airflow strategies.

Further, as the system boundary under consideration expands, opportunities for assimilating incremental strategies — specific materials or assemblies — become more apparent, allowing for embedded strategies to develop.

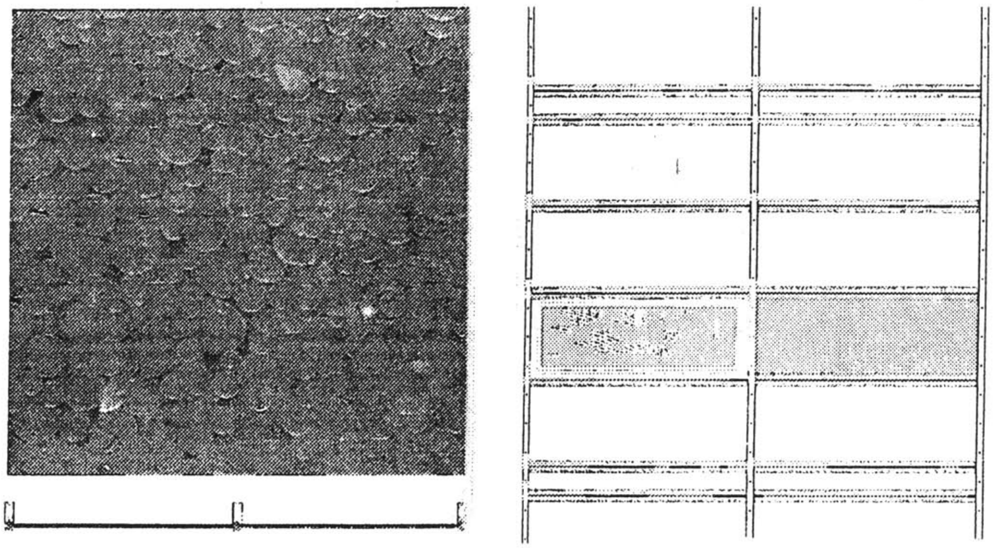


Fig. 15 Thomas Herzog, Silica Gel Glazing Material

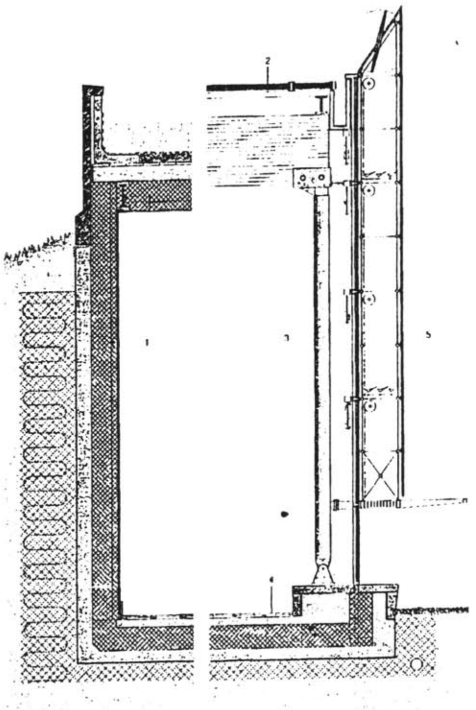


Fig. 16 Arup Associates, Dynamic Envelope System

Materials and Molecular Behavior

Developments in material science have expanded the vocabulary of behaviors which become possible as the result of an enclosure element. Typically these advanced materials allow for increased thermal resistance within a pane of fenestration without eliminating access to daylight. In some applications, a clear panel can be made opaque with the transmission of an electric current, hinting at the kind of environmental interactions possible either through active or passive means.

Surfaces and Boundary Conditions

The transition from the application of discrete material-intensive strategies to ones which define surface areas is demonstrated by the following examples. These projects vigorously address the layer between inside and outside of the building, but this intensity does not appear to affect the treatement of the interior spaces based on this threshold. In addition, these enclosures limit the degree of interaction between inside and out, leaving the occupation of the spaces a hermetic experience, if partially mediated by the envelope surfaces.

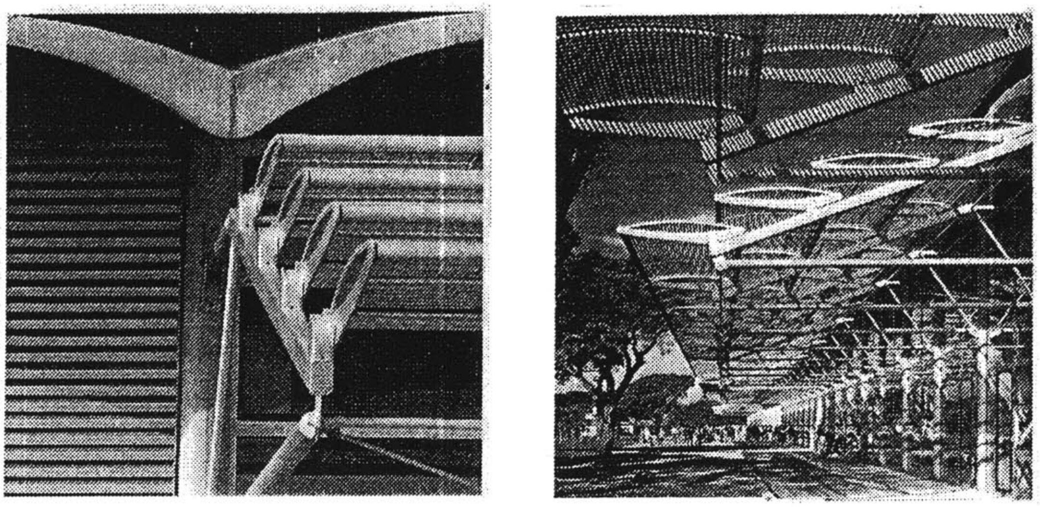


Fig. 17 Norman Foster, Sun Shading Device

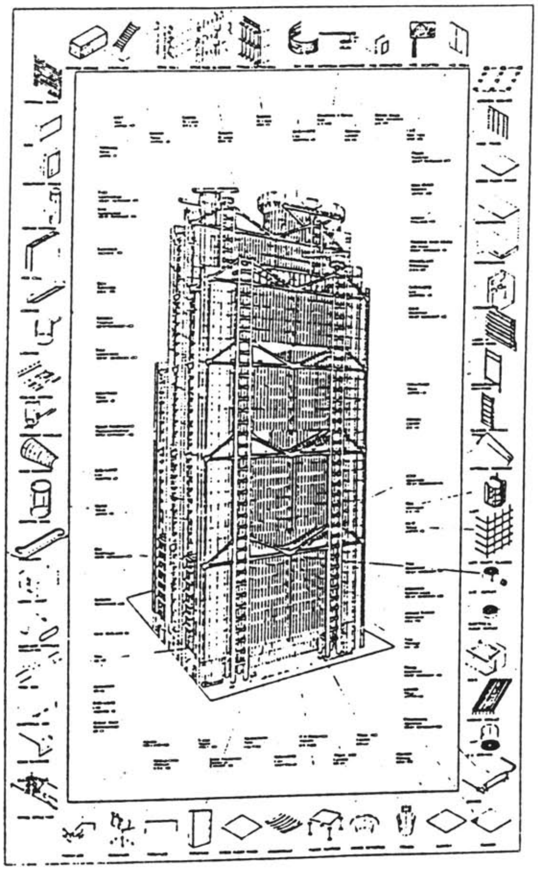


Fig. 18 Norman Foster, Hong Kong Bank, Element Diagram

External Elements and Peripheral Conditions

Typified by attachements to the exterior of the envelope, these elements can have siginficant advantages in shading unwanted solar gains, collecting solar energy, and protecting the exterior of the building from weather, while possibly collecting water for reuse. However, this approach often takes a reactive stance towards these natural forces, and while defining an external image, seldom directly affect the internal organization of spaces.

Sectional Assemblies and Construction Sequence

This definition of system boundary applies to strategies which make use of pre-fabricated assemblies whose performance criteria are designed for low-energy uses. Technological innovations of this kind are advancing our knowledge about the integration of manufacturing processes as a means of engaging building form within a variety of environmental conditions. A "kit of parts" approach can simplify the design process and promote the consideration of life-cycle replacement and recycling criteria.

As these developments in technology and procurement evolve, architects will have the potential to design prototype elements within a class of assemblies which can be tuned to the specific to the needs of their building and site.

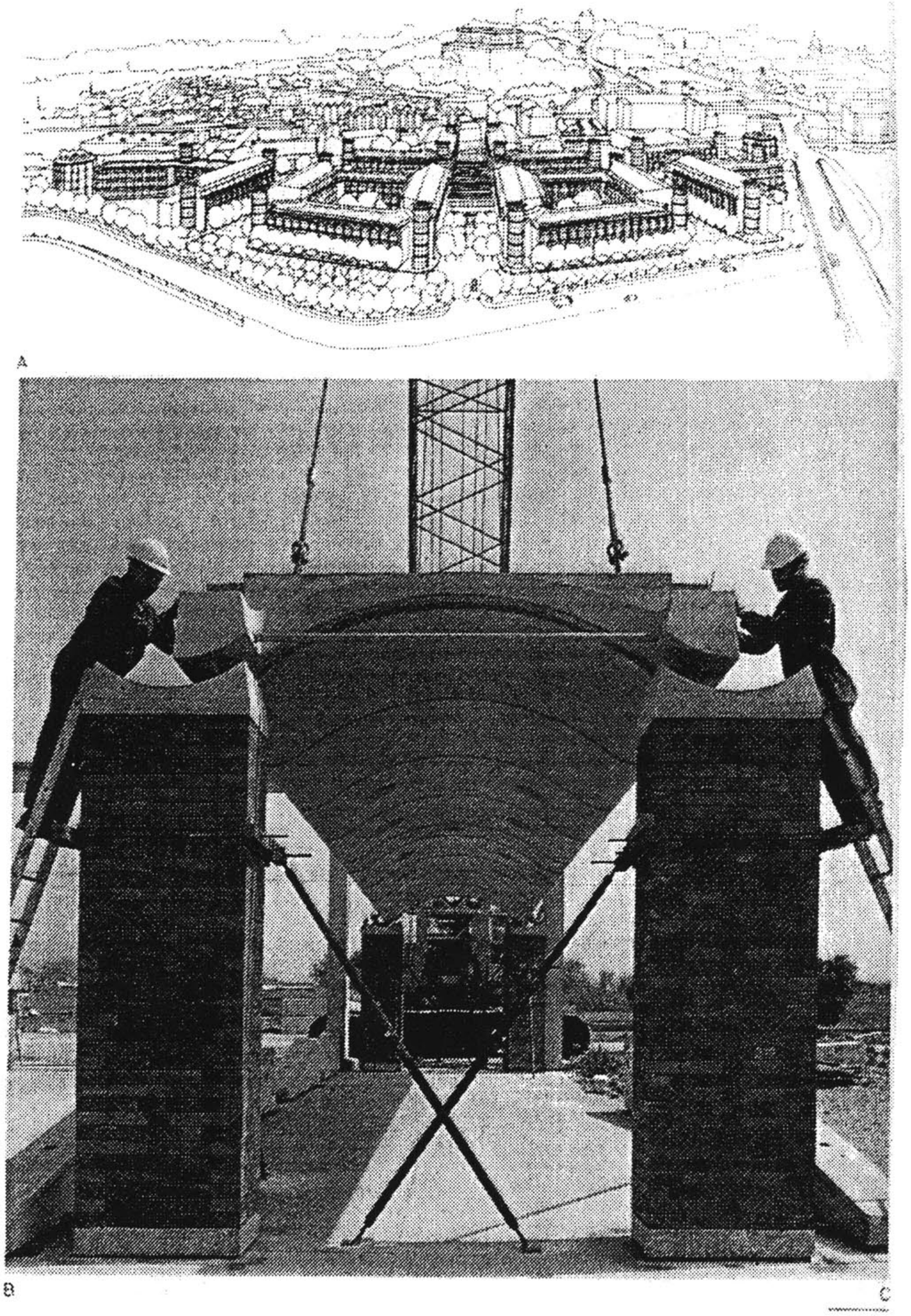


Fig. 19 Michael Hopkins, Inland Revenue Centre, Site and Elements

Spatial Organization and Tectonic Legibility

The most comperehensive design strategies demonstrate a holistic approach to the design of the envelope in which the form and use of the interior spaces directly correspond to the technological manipulations of the materials, surfaces, and assemblies which enclose them.

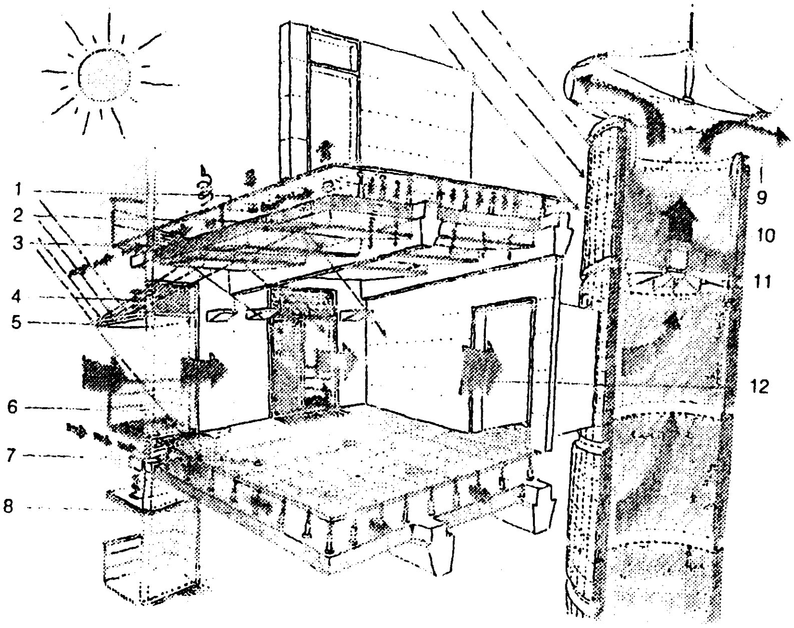


Fig. 20 Michael Hopkins, Inland Revenue Centre, Environmental Interaction

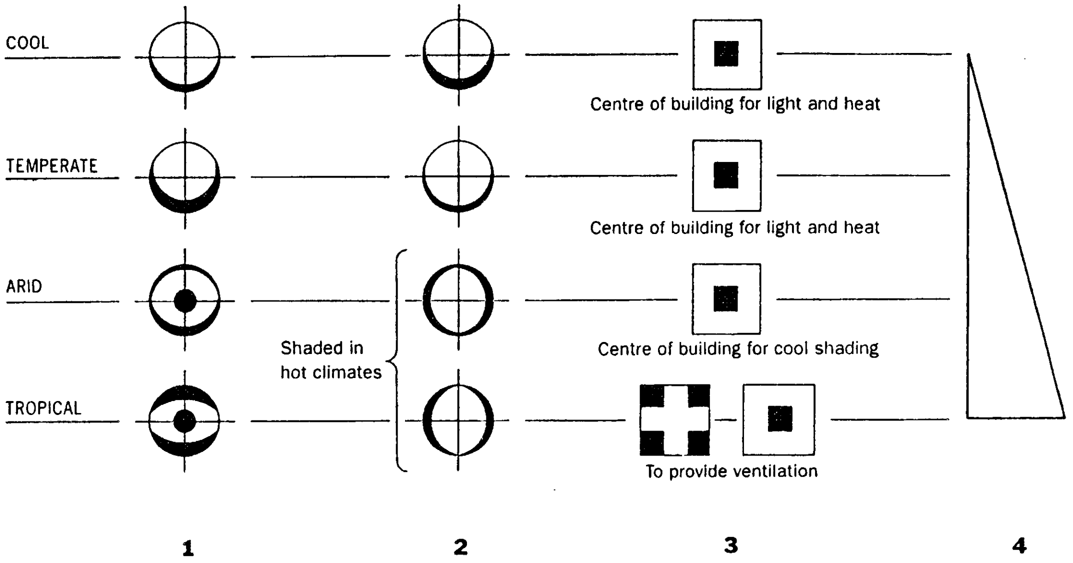


Fig. 21 Ken Yeang, Bioclimatic Design Strategies for Daylighting

A Bioclimatic Approach

Redefining the Modern Vernacular

The evidence found in contemporary architecture suggests that even progressive solutions to a low-energy mandate can lack a deeper, more holistic appreciation of the relationship between building form, the use of space or territory, and the conditions particular to the surrounding environment. Architect and educator William McDonough has observed that architecture in the past few decades is a “monument to the designer’s ignorance of where the sun is”[1], notably the multitude of monolithic urban buildings with identical four-sided envelopes in complete denial of their vastly different climatic loads.

The preceding study of building envelope systems reveals the technological opportunities which have come about as a result of low-energy or environmentally responsive intentions during the design process. Yet these examples, with rare exception, tend to shift the focus towards the exploits of the technology itself, instead of engaging the building’s occupants to consider, even to influence the manner in which they dwell with the environment.

A fundamental question of this Thesis has been to develop an understanding of how vernacular architectural principles can evolve to serve the requirements of modern, urban, commercial buildings. Much of the recent work investigating vernacular form has centered on rural and often pre-industrial precedents, yet there is a pressing need to regenerate the powerful relationship between urban form, building fabric, and a collective understanding of how to inhabit them as mediating elements in our daily lives.

Critical debates about style have tended to focus on facade issues — drawing attention to the surface appearance and image quality of a building, and away from the processes that underlie its construction and subsequent interactions, be they social, physical, or cultural[2].

Any progress from such a condition requires a more comprehensive framework than simply a low-energy mandate. In the interest of developing a more holistic appreciation of this problem as an architectural question, the issue can be phrased in terms of a "bioclimatic approach" which takes into consideration the complexities of biological systems and the realities of a particular climate.

As such, an example of vernacular architecture represents the specific instance, in the artifact of a building, of a bioclimatic process — an act of creation responding to and engaging the environment. What follows is some pathfinding along these principles which may allow designers to exercise their architectural knowledge in order to reinvent the modern urban vernacular.

Like so many classifying words, the word "vernacular" has of late acquired a perplexing amount of nuance, allowing itself to confuse rather than clarify its associations. A nascent interest in this genre promises to invigorate the dialogue regarding place-making within the bounds of stylistic innovation[3]. However, much of the discourse remains within the limits of traditional typologies, again, often rural in their instances. It is useful, therefore, to qualify attempts at a modern vernacular within the specifics of its original definition.

Writer and landscape architect J. B. Jackson interprets this definition to have first been phrased by the English architectural historian R. W. Brunskill in his work A Handbook of Vernacular Architecture, published in 1973. Brunskill says that a vernacular style is the embodied in the creation of local building traditions, using forms, materials, and techniques long familiar to the region. The design of a vernacular dwelling is furthermore the product of a local artisan or of the prospective occupant. The basic forms are domestic in origin, and the style emphasizes continuity, while maintaining a strict regard for function[4].

Jackson notes that this understanding of vernacular style tends not to welcome radically new techniques, or materials imported from elsewhere. He further points out that according to this interpretation, vernacular architecture ceased to be produced at some point in time, depending on regional circumstances — presumably upon the expansion of cultural boundaries by improvements in transportation.

Hence, in its reluctance to take on new ideas and techniques, and in its loyalty to historical types, Brunskill's vernacular stands outside of an architectural discourse which calls for continuous innovation and progressive technological integration.

The one aspect of Brunskill's definition which does, however, embody relevant design possibilities is the deterministic attitude through which vernacular form

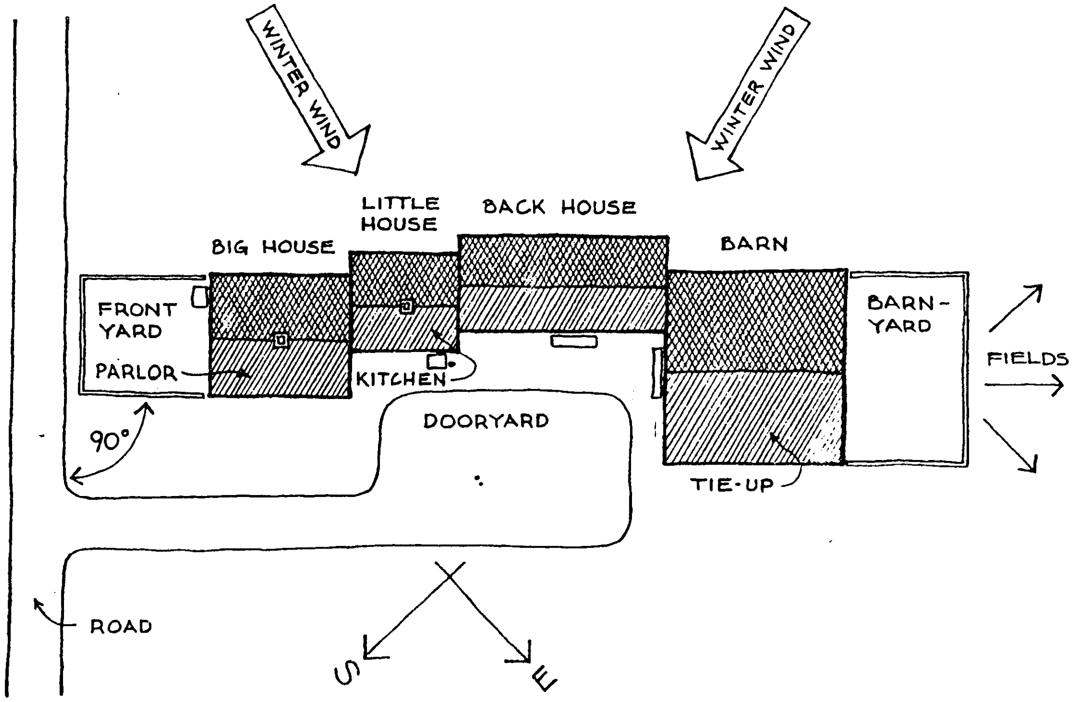


Fig. 22 Thomas Hubka, New England Farm Buildings: Site Elements

extends itself towards the natural environment — the integration of soil, topography, and climate in the form of a building. This direct relationship to local natural settings has over time encouraged the proliferation of a rural bias, and a separation from the economic and technological aspects of dwelling. By layering a theoretical blanket on the dialectic between nature and architecture, writers including Heidegger, Eliade, and Jung further polarized the existential dimensions of dwelling from more practical ones.

In a study tracing the historial development of a New England building type, architect Thomas Hubka has analyzed the evolution of connected farms according to patterns of construction, usage, and change over time[5]. While the stylistic implications of this study are consistent with a conservative attitude towards change, the importance of this building type is the specificity with which building form is manipulated to create original microclimates where open land existed before.

The pervasive manner through which territory is assimilated and changed over time, based on its social functions and seasonal circumstances, reflects a direct engagement of natural phenomena through tectonic elements. These bioclimatic strategies can be directly mapped to the design of contemporary buildings, making use available technology, and providing similar capacity for change as either the climate or specifics of social function evolve over time.

The subtle yet sophisticated lessons demonstrated by the connected farm buildings of New England have distinguished parallels in modern design. These

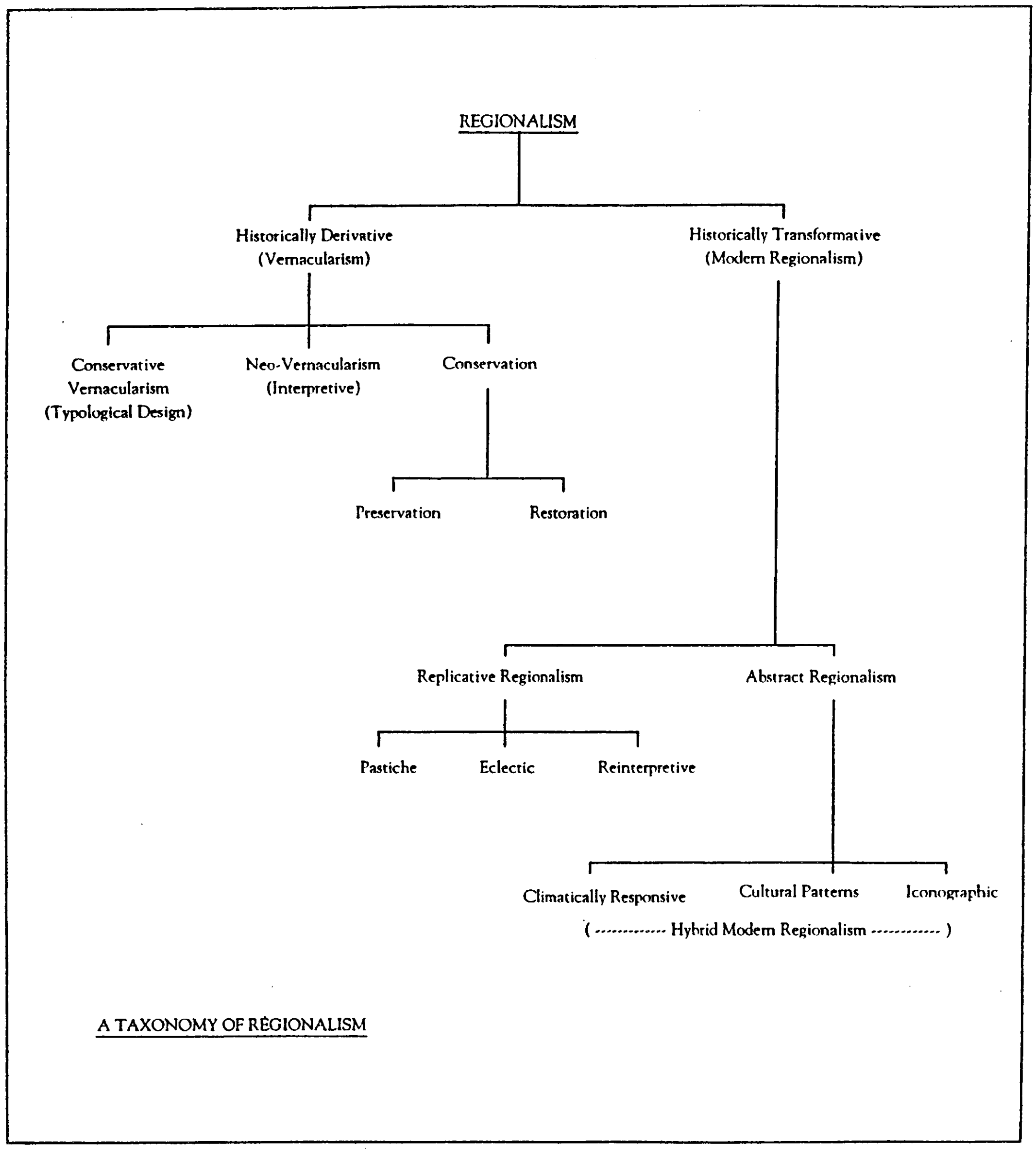


Fig. 23 Kenneth Powell, A Taxonomy of Regionalism

includeAlvar Aalto's continuous interpretation of light, specifically the northern light of his home region, resulting in a characteristic form language which is both innovative and sensitive to the site. By returning to the importance of climate and site as form-finding criteria, a bioclimatic approach allows for endless innovation within the bounds of intended performance.

This opportunity in fact underscores the flexibility of true vernacular form, and the emphasis on adaptation over time which is subtly missing from Brunskill's snapshot definition. Innovation, therefore, has to be included in a modern reinterpretation of the vernacular, be it urban or suburban. The notion that any artifact of history is a static in its measure can be misleading, since its existence — perhaps even its fortuitous survival — involves a complex matrix of social and physical elements which define the artifact as it evolves.

"There is a common chord in all this [building] that will be heard; and it is not a plea for ugliness. It is a plea for first principles -- for less heat and parasitism, more light and pragmatic integrity; for less architecture in quotation marks and more engineering.

I feel that the sceptre has all but passed from the hands of the architects to the hands of the engineer, and if it is ever to be the architect's again, [s]he must take it from the engineer by force of superior virtue."

-- *Frank Lloyd Wright*, 1909
[responding to a critic's evaluation
of the daylighted Larkin Building]

Architectural Knowledge

Learning Function through Form

The antecedents of a deterministic architecture based on function can be found as early as the mid-eighteenth century. With the advent of modernism, arguably coincident with the increase in attention paid to the sciences and their methods, discourses in architecture developed a penchant for postulating rule-based laws by which design could elevate itself with the rising culture of scientific endeavors.

The outfall of this empirical focus is still evident today, albeit in a supposed counterreaction to the formulation of rules and dictums for explaining or informing design. Working someplace between the service, manufacturing, and professional sectors, architects have grown to become suspicious of constraints to their creative efforts. What could now be interpreted as constraints or limits, however, were historically a collective effort to position the epistemology of architectural design in an applicable frame of reference. In short, the movement towards a science of architecture did not set out to subvert building form, only to provide its designers with the benefits of the latest knowledge, both theoretical and practical.

Manfredo Tafuri reports on the contemporary results of this tension between process in product as the "theoretical knot that must be confronted" in order to

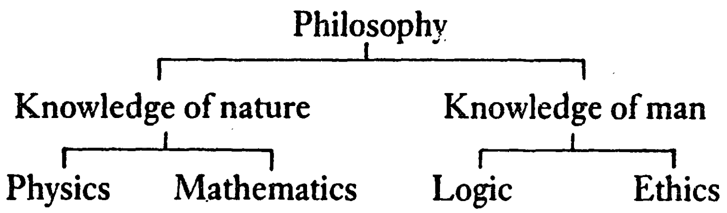


Fig. 24 Nature and Man

arrive "at the heart of those [design] strategies — arriving, that is, at their modes of production"[1]. This attention to the design of design may appear too self-conscious, even self-referential at times, yet its reoccurence underlines the notion that one cannot successfully make architecture with architecture alone, rather one must make architecture through an understanding of life — in whatever direction that "life" is interpreted.

The story of late nineteenth century theoreticians is the story of attempts to interpret and understand the notions of utility and function through architectural form. Among the questions which remain ideologically current, the ones which this Thesis poses are:

- what is the basis for knowledge about design ?
- how is this knowledge applied as a means towards an end ?

In its barest phraseology, architectural knowledge can be defined as the process by which designers assimilate materials into the form of a building for the purpose of inhabitation or sheltered use. The implications of this process, and the consequences of their results, are the basis for studies beyond the scope of this discussion. The essential argument presented here is that the creation of space — the making of architecture — is a formal response to a matrix of needs and requirements. This response is also one of the most lasting and continuous processes known to our civilization. Therefore, how is it that designers interpret this matrix, or more importantly, establish one in the first place ?

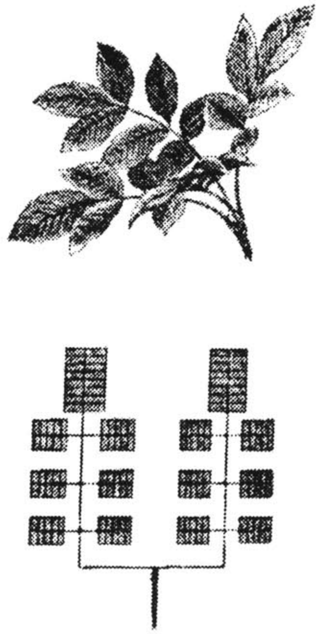


Fig. 25 John Ruskin, Hierarchical Form

Vernacular form was often synonynous with a "spontaneous" process clearly outside of the territory claimed by professional designers, yet the buildings which result from this process often embody a clarity of knowledge about materials, uses, and climate which appealed to those architects sensible enough to notice. Believing that some aspect of this knowledge lay in the natural sciences, the task of theorists amidst the industrial revolution was to make use of scientific methods as the basis for connecting theories of form with the practice of design.

Writer and philosopher Francis Bacon was directly influential in supporting a connection between theory and practice, whereby the former might lead to an understanding of the latter[2]. Bacon encouraged an identification of the universal principles which underlie real technical phenomena. The nascent methodologies propagating in the natural sciences appeared ready to support this endeavor, and this process to a great extent defines the philosophical base of the Enlightenment Period.

The close relationship which was presumed to relate form and technique was the basis for justifying claims to both architectural innovation as well as stylistic retrenchement. Among those theorists who attempted to clarify the relationship between aesthetics and construction, Gottfried Semper was particularily advanced in his efforts to account for innovative form-making through the application of specific design principles drawn from outside the methods of architectural production[3].

While John Ruskin did emphasize the importance of analyzing hierarchical structures within natual forms,

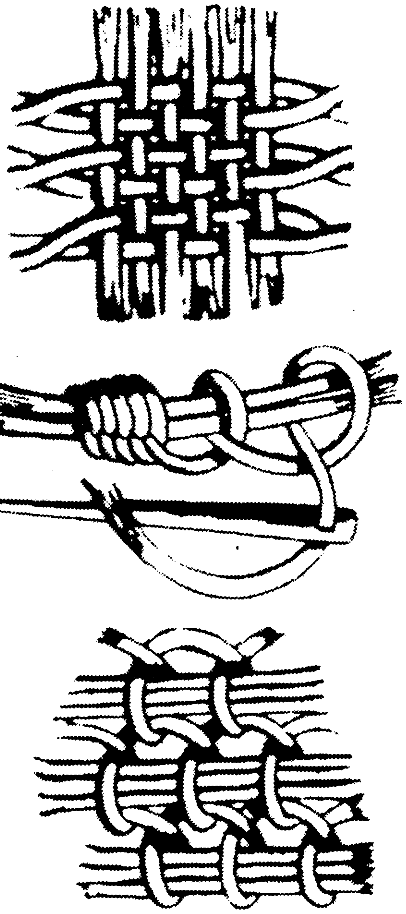


Fig. 26 Gottfried Semper, The Weaving Craft

his concept of a "truthful" form tended towards a reductive rather than synthetic reasoning. Likewise, E.E. Viollet-le-Duc believed that the truth of a formal style lay in the extent to which a hidden order of relationships became evident, and led directly to the construction and form of a building. Although he did argue that the developments of new materials and production methods necessitated new forms, his consideration was restricted to the systematization of constituent parts based on their interrelationships. The principles for which he was an able spokesman did not overtly extend to a holistic framework which included the natural environment as the site and context of architectural form.

Gottfried Semper was critical of architectural theories which tended towards a mechanical aggregation of elements. Instead, like Bacon, he sought to understand first the principles of organic law as the basis for creating formal relationships[4]. His interest in these principles evolved according to his interest in architectural "function", an understanding which was richer than that of his contemporaries and still valid today.

Semper's most important writing on the subject of style in the technical arts, <u>Der Stil</u>, emphasized the interrelationship of form and technique[5]. According to his ideas, any artifact was considered the result of a creative process which took into account a series of parameters[6]. Semper borrowed from the sciences a generalized notation by which $Y = F\{ x,y,z,etc... \}$ represented the variables for design. These variables included utilitarian factors as well as the importance of symbolic expression[7].

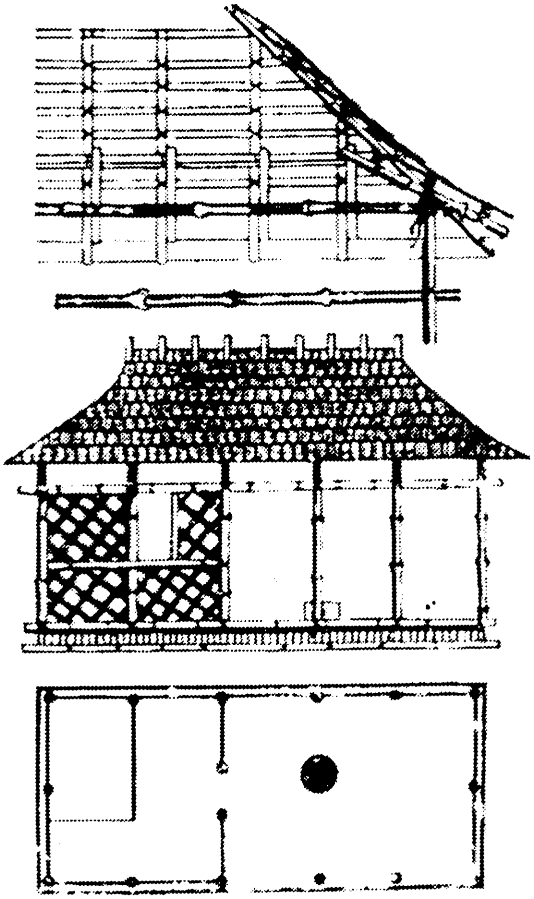


Fig. 27 Gottfried Semper, Vernacular Hut

In his clear attempt to represent architectural knowledge as a set of functional relationships, Semper did emphasize the importance of innovation and creativity as much as any technical of material influence. By casting the symbolic aspects of form into the realm of his abstracted scientific discourse, he may have been buying some freedom for the justification of form on a symbolic basis alone. However, his interests were more clearly directed towards a systematic adaptation of the mathematical thinking he found attarctive in comparative sciences and the vernacular production techniques he believed formed the basic elements of architecture.

Scientific advances in the practical knowledge of systemic behavior led theorists of the Enlightenment period to the determination of a "calculus" which was useful in determining the apparent regularity of any physical change in nature. Semper openly wondered whether reality as a whole was governed by mathematical principles[8], and whether such laws could be derived for a variety of cultural domains which exhibited less empirical evidence of behavioral patterns, but followed patterns nonetheless.

In his efforts to substantiate the existence of a principled framework for the evolution of form, Semper sought to define the basic elements of architecture. The basis for defining the base, hearth, walling and roof were not only practical in nature but directly associated with their symbolic purposes. As each primary human situation, therefore, became known in terms of both its mythical and functional relationships

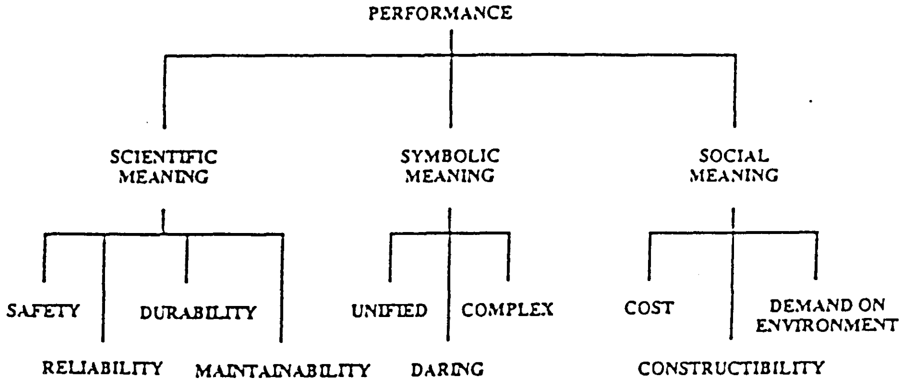


Fig. 28 Levels of Performance in Architecture

to building elements.

Semper's concept of "function" was both comprehensive and universal in a way that may be difficult to fully understand today. Only by stripping both its mythical and mathematical substance can we recognize the contemporary use of the word and measure its effect on modern design[9]. While Semper's writings became popular in Europe, and later in the US via Chicago, the fundamental importance of his framework for design — the symbolic aspects of form and the human experiences from which they stem — became lost in favor of a more deterministic formulation in which "form followed function", according to Sullivan.

Reduced to technological imperatives and the consequences of economies of material, this derivative use of "function" lacked the essential connections to the ideas described in Der Stil. For Semper, a function was to be a calculus of the relationships inherent to the variables of the design process, which were understood as unlimited and changing.

Semper further distinguished between "intrinsic" variables — belonging to principles of natural law: symmetry, axiality, properties of materials, and the like — and those "extrinsic" to the work itself. Of the latter, he included local influences, matters of climate, politics, social habits, and so on [10]. The design of a building, therefore, was inconcievable without the multiple factors of its embodiment, yet Semper believed that a single, formal purpose determined its formation, ruling the inner logic of its development[11].

The separation of form and content which defines current theoretical discourse prevents a clear appre

Table 5. Three Ways of Being-with Technology

	Basic Attitudes		
Conceptual Elements	Ancient Skepticism (suspicious of technology)	Enlightenment Optimism (promotion of technology)	Romantic Uneasiness (ambivalent about technology)
Volition (transcendence)	Will to technology involves tendency to turn away from God or the gods	Will to technology is ordained by God or by nature	Will to technology is an aspect of creativity, which tends to crowd out other aspects
Activity (ethics)	Personal: Technical affluence undermines individual virtue Societal: Technical change weakens political stability	Personal: Technical activities socialize individuals Societal: Technology creates public wealth	Personal: Technology engenders freedom but alienates from affective strength to exercise it Societal: Technology weakens social bonds of affection
Knowledge (epistemology)	Technical information is not true wisdom	Technical engagement with the world yields true knowledge (pragmatism)	Imagination and vision are more crucial than technical knowledge
Objects (metaphysics)	Artifacts are less real than natural objects and thus require external guidance	Nature and artifice operate by the same mechanical principles	Artifacts expand the process of life and reveal the sublime

Fig. 29 A Technological Epistemology

ciation of Semper's belief in a building's function. Much of this discourse marginalizes any attempt to direct design by means of empirical principles, but this view misses the point of Semper's assimilation of scientific methods and cultural anthropology in the service of architectural form.

As a theorist, Semper wondered about the relationship between geometry and conduct, between form and behavior. He emphasized the potential of an integrated framework within which spatial order, formal purpose, and organic law responded to a flexible matrix of principles. While this framework continues to evolve with our expanding knowledge of the natural environment, the argument for defining the elements of such a matrix is still currently valid.

The need for a clearly defined framework for the application of architectural knowledge is especially relevant in cases where architecture and technology are combined with the interest of mediating those extrinsic variables specific to climate, since this direction is prone to considering functional aspects alone, and ignoring the capacity and importance which Semper placed on tradition, innovation , and symbolic expression[12].

Since analysis of climatic conditions alone cannot provide insight for an architectural response to individual natural phenomena, this Thesis proposes to look at current scientific models which aim at a deeper understanding of behavior in a variety of natural — and by extension, cultural — processes. This direction is motivated by a strong belief that the application of architectural knowledge to technical problems must be informed by such scientific knowledge. Failing to do so

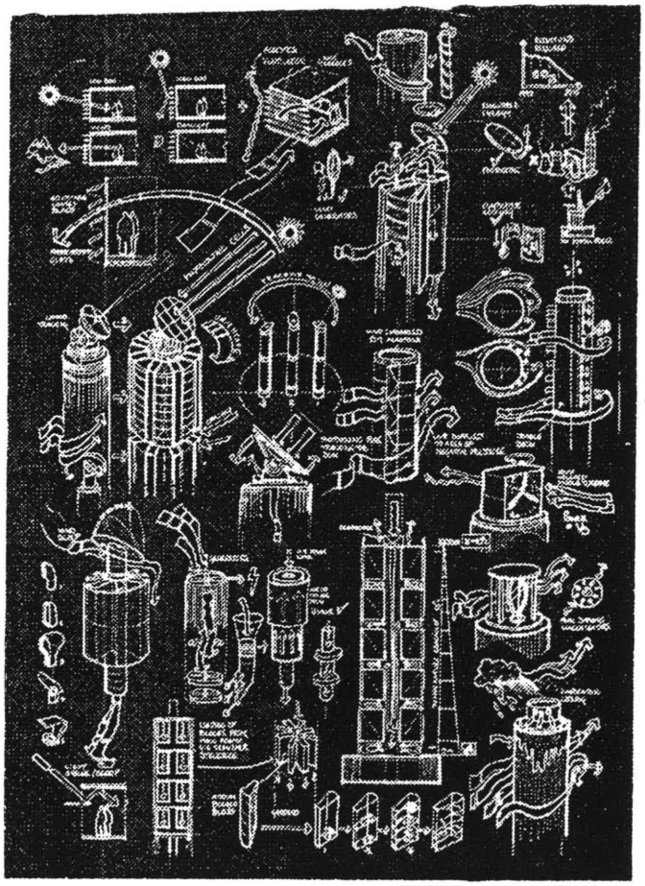


Fig. 30 Battle McCarthy, Design Exploration for a Tropical Tower

is an abdication of our relationship with nature to the functions defined by “machines for living”.

Therefore, one vision of how to dwell with the environment is to broaden our understanding of the way in which natual systems behave, and explore how an intervention in these systems — an act of building — reacts within their boundaries. Just as there exist many practical reasons for re-establishing a balance between the ecosystems of man and nature, including a reduction in pollution and a conservation of economic and material resources, there are also incentives for a conceptual redefinition of the architect’s role as a synthetic collaborator.

Without a sound appreciation of the physical and social ramifications of a design proposal, an architect in current climates risks finding a limited role — and a surface one at that — in the definition of our collective environment.

“Symbolic analysts, who identify, broker, and solve new problems, are by and large succeeding in the world economy... The education of the symbolic analyst emphasizes systems thinking.”

-- *Robert Reich*
The Work of Nations[1]

Systems Dynamics

Principles of Behavior in Natural Phenomena

If architecture can be reinvested with a sense of responsibility for its physical and cultural context, it follows that within such a condition, there should exist equal measures of a potential for wonder and a capacity for function. An accurate course of action for such a holistic design strategy would be a clear set of objectives based on an iterative evaluation of the design proposal within an expanding set of system boundaries.

In the best of circumstances, traditional design practice seldom allows for such a controlled adventure in discovery, even towards an agreed upon end such as a low-energy objective. Instead, as creative designers we rely on a generalized set of heuristics based on experience, common practice, and problem solving techniques.

Design innovation in this context can prove difficult, however, without an appreciation for the manner in which a proposal succeeds in meeting the overall complexities of a particular building or program, especially one which involves technical challenges.

While the use of system boundaries can be helpful in exploring design principles in their smaller instances, removed artificially from the larger context, these boundaries can also be misleading in their suggestion

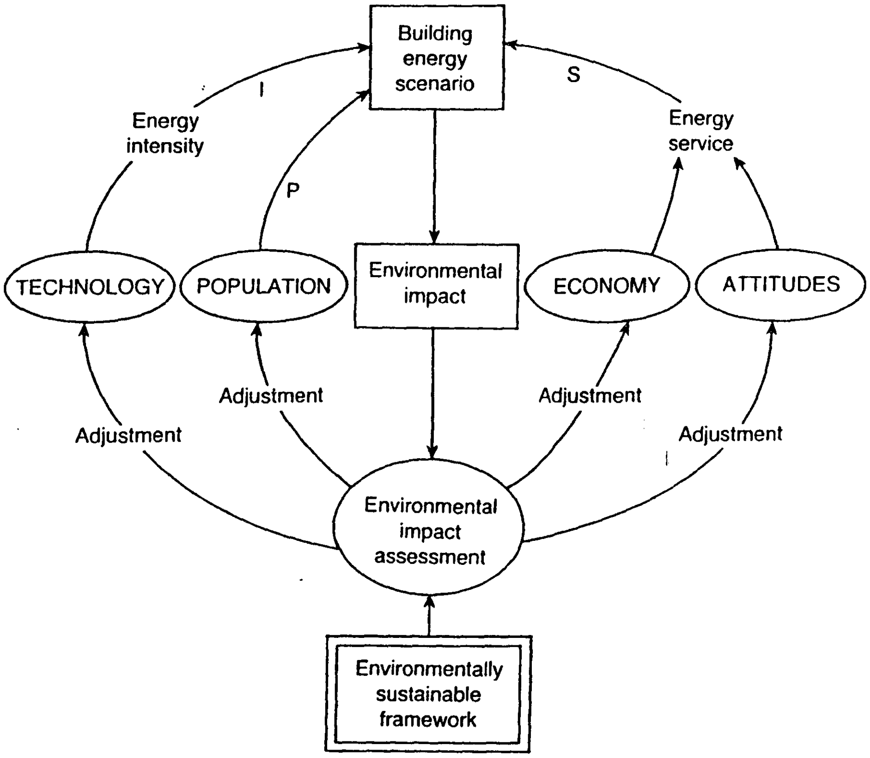


Fig. 31 Aspects of a Sustainable System

of actual performance — whether spatial or physical. Semper and his colleagues were diligent in outlining the importance of a clear symbolic expression, yet did not specify with any precision how the variables of a design problem could be sorted out or prioritized. How then to apply architectural knowledge ?

In the case of this Thesis, investigating a bioclimatic approach to the problem of integrated design, it was necessary to become educated in the realities of behavior in physical phenomena prior to proposing any integration with this behavior. This lead to a study of what has become known as "complexity theory" or "non-linear dynamical systems theory".

Hardly established long enough to take its place among the natural sciences, complexity theory is an ongoing, interdisciplinary quest to answer questions about some of nature's most common phenomena, which turn out to have very complicated answers. In fact, more often than answers, these questions lead to a better understanding of phyical and social phenomena, recognizing that instead of predicting behavior, science can only sometimes characterize the possibilities and outcomes, thereby leaving it to direct experience for the final measure of reality.

The importance of this study is the understanding that people, buildings, and phenomena are connected in very sophisticated ways. The most lucrative approach to a design problem, in terms of its effect on the system, is therefore one which takes a broad view of the design context and yet accounts for the important details of form, behavior, and their systemic interactions .

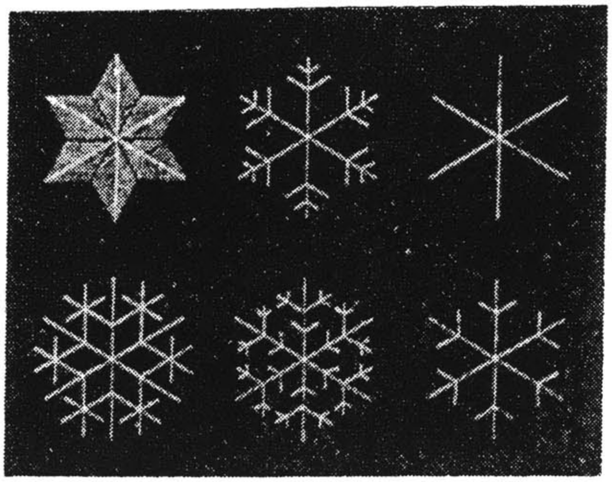


Fig. 32 Gottfried Semper, Snowflakes

The categories of problems which dynamical systems analysis finds on its desktop are as wide and unrelated as imagineable. They range from issues in population, economics, physics, and biology to the realm of artificial intelligence, social interactions, and the structure of the universe.

What they have in common is that each question, embedded as it is in its particular context, is complex; specifically, each question involves many independent agents or pieces of the problem interacting in a great many ways. In addition, the essential richness of these interactions allows the system as a whole to undergo evolutions — often several and continuous — of spontaneous self-organization[2].

Organisms, for example, constantly adapt to each other through evolution, organizing themselves into environments we recognize as ecosystems. One of the hallmarks of such ecosystems is their ability to adapt, turning their circumstances into an advantage for survival or development. Many complex systems exhibit the capacity to adapt — organizations of people, wildlife, and matter — such that it has become a characteristic sign of complexity.

Last, these systems exhibit a dynamism that separate them from static objects such as snowflakes and computer chips, in that they respond to the ebb and flow of energy in a spontaneous manner, never repeating the pattern, yet not so dynamically as to qualify as chaotic.

Chaos theory has shaken the foundations of modern science in the last twenty years with its explanation of

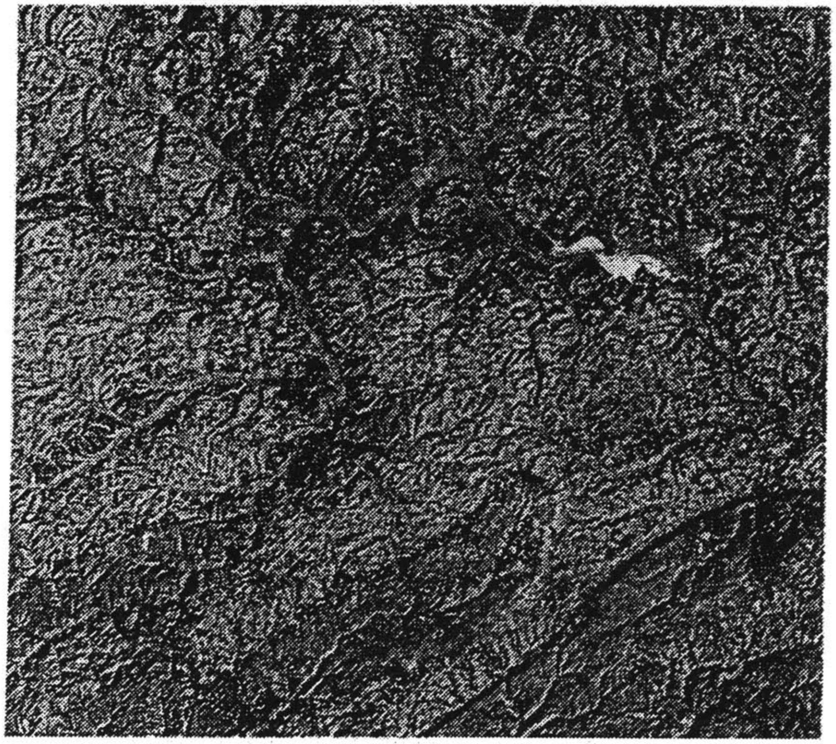


Fig. 33 Fractal Landscape, Aerial Photograph

how very simple rules can give rise to extraordinarily complex behavior. Chaos theory by itself, however, does not explain the underlying structure, patterns, and guiding principles behind coherent, self-organizing complex systems[3].

The qualifying characteristic of a complex dynamical system is the innate or acquired ability of the system to bring order out of apparent chaos, and keep a certain fluid balance amidst its constituent agents. Examples include the flocking of birds or the schooling of fish, the fluctuations of the stock market with its hundreds of floor traders as adaptive agents, and the flow of air and water in characteristic patterns. What is it that binds these systems to one another and to what principles do they adhere ?

Physicist Ilya Prigogine, Nobe Prize Laureate in 1977 for his work in “non-equilibrium thermodynamics”, addressed the question in terms of the origins of order and structure in the world. Considering the world’s tendency to decay, know as “entropy”, natural forces when left to themselves appear to be perpetually engaged in destruction — codified into the second law of thermodynamics[4] — yet our natural world also reveals a great deal of order and growth.

In reconciling this emerging structure with the second law of thermodynamics[5], the answer to the riddle of order is to look carefully at the question: in the real world, lacking the abstraction of system boundaries, atoms and molecules are almost never “left to themselves”, but rather are continuously subject to flows of material and energy across their boundaries[6]. If such

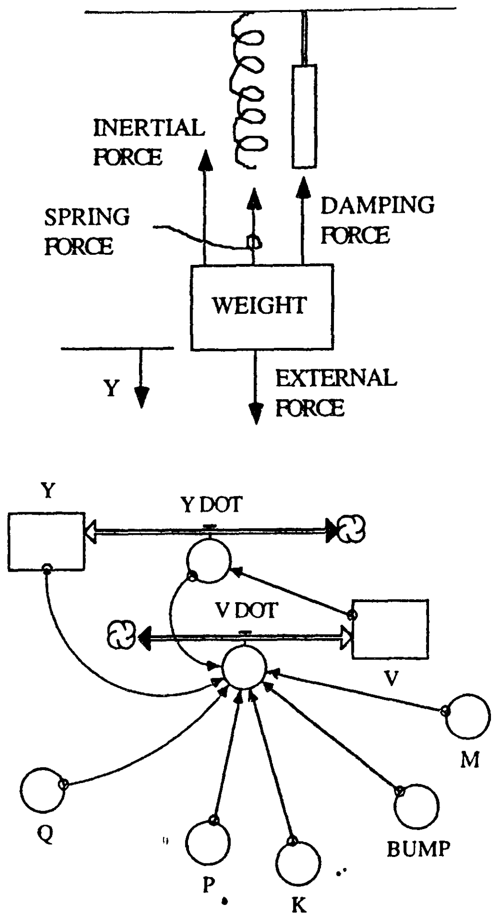


Fig. 34 Spring and Damper Model

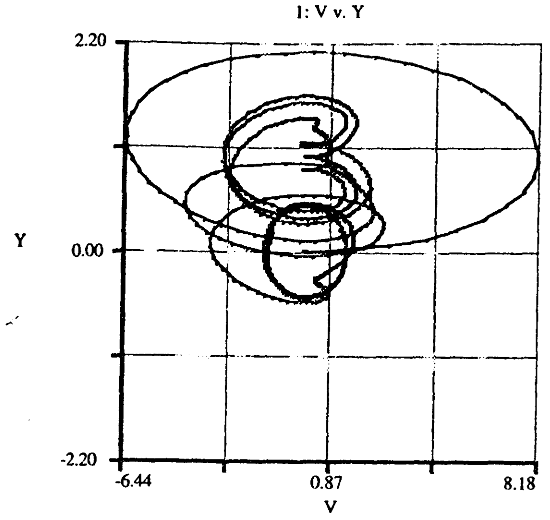


Fig. 35 Phase Plot of Spring Mass Location

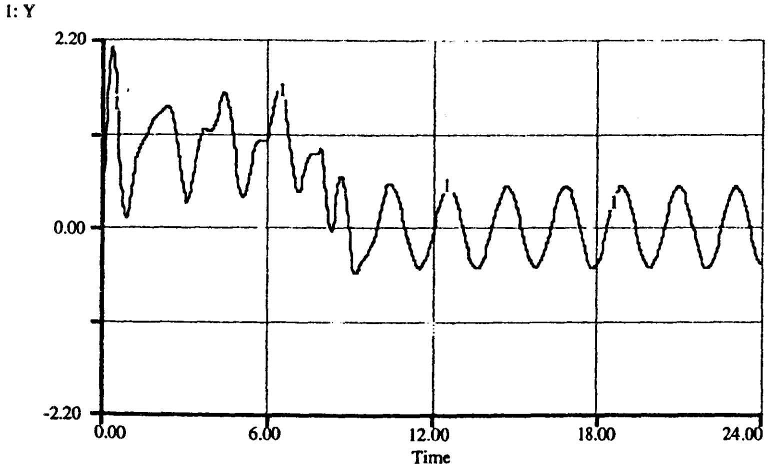


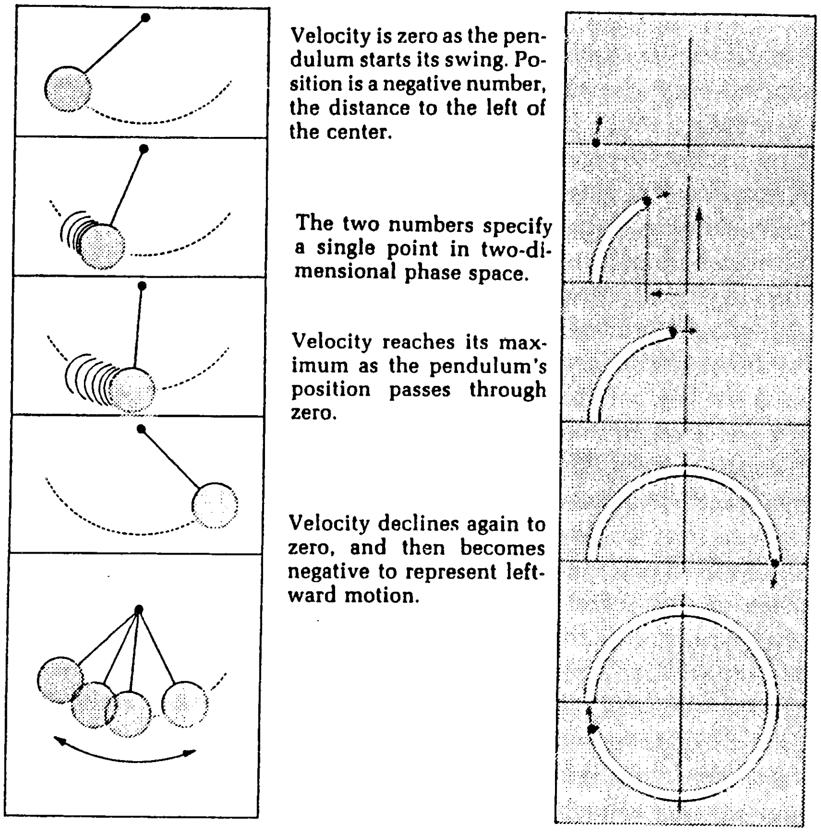
Fig. 36 Time Plot of Spring Mass Behavior

flows are strong enough, the system's entropy can for a short time even be reversed. Within a particular physical region — a pot of heated soup or a patch of stormy sky — a given system can spontaneously organize itself into a series of complex structures.

As we learn to recognize them, self-organizing structures seem to propagate in nature with ubiquitous tendencies, and Prigogine set to branching out his theories and applying them to a broader class of issues. This task allowed him to clarify another important characteristic of complex dynamical systems, that the self-organizing tendencies of these systems depends upon self-reinforcement[7]. In engineering terms, this tendency is understood as positive feedback, and is described mathematically by a specific function's residual element and its tendency to "explode" an iterative operation instead of stabilizing.

This non-linearity is a point of departure from the kind of scientific knowledge Gottfried Semper had access to upon formulating his contextual mapping of positivist methods into architectural theory. The direct functional statement of $Y = F \{x, y, z\}$ is a linear construct whose behavior mathematically usually results in a simple, often straight line when mapped as a graph, representing an equilibrium state for the function in question. We now know through observation and conceptual formulation that the real world of natural phenomena, and that of complex dynamic systems, does not behave that way.

This fact may be a dissuading factor for a designer not trained in numerical integration techniques, but mathematics are in this case not the primary obstacle to developing an appropriate proposal whose behav-



Velocity is zero as the pendulum starts its swing. Position is a negative number, the distance to the left of the center.

The two numbers specify a single point in two-dimensional phase space.

Velocity reaches its maximum as the pendulum's position passes through zero.

Velocity declines again to zero, and then becomes negative to represent leftward motion.

Fig. 37 Phase Plot of a Simple Pendulum ior can be understood in terms of reasonable expectations. An appreciation for the principles of behavior exhibited by natural phenomena — the very knowledge that they behave in a non-linear fashion, with a sensitive dependence on initial conditions — is sufficient to be able to make use of a variety of tools, both intellectual and computational, in order to construct a relevant architectural proposition with the capacity for development as a technical problem.

It is important to clarify that the role of technology, in this case, is to support the bioclimatic values inherent to the design agenda, allowing for those values which are most important — those which relate a spatial construct to the specific uses in question, for example — to be revealed through a low-energy tectonic.

This hierarchy of use / form / climate / technology allows the application of architectural knowledge to influence downstream activities from design development to fitting out the final building.

An understanding of the characteristics of complex dynamical systems and the tools with which to investigate them can only strengthen the role of architectural knowledge. In this sense, the bioclimatic approach can itself become a self-reinforcing system as the design process moves along, gathering feedback and necessary momentum.

The most insightful tool of the systems analyst is called a “phase plot”, and represents a solution space for the behavior of a particular phenomena under real or experimental circumstances. Although such math-

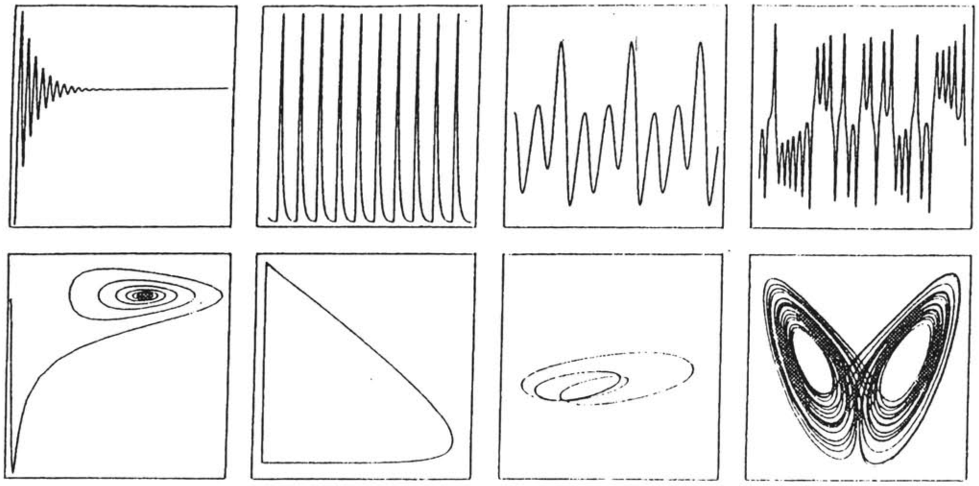


Fig. 38 Phase Plots below Ordinate Plots

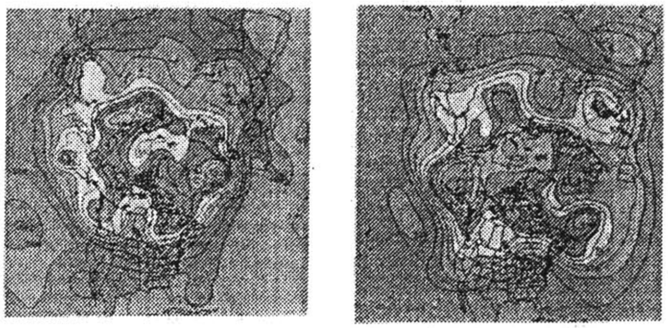


Fig. 39 Diverging Weather Patterns

ematical visualizations have been available for longer than the methods of complexity theory, it is most useful as a means of observing not just a single possible outcome but an entire set of possible solutions for a specific set of criteria.

The reason this aspect of phase plots is so relevant is that, as outlined above, natural phenomena are not predictable in terms of their actual behavior. They do, however, exhibit self-organizing tendencies both at the molecular level and as larger organisms. Consider, for example, the similarities between a tidal eddy and a tornado, namely the tendencies of each to turn around a specific point and to move over time. Phase plotting the trajectory of a point in such a phenomenon can classify the behavior of other points in the fray, and yield some knowledge of its behavior.

Once accustomed to reading phase plots, one can recognize that certain phenomena appear to "gravitate " around points on the phase plane. These points are called "attractors", and determine the manner in which the global behavior of a phenomenon can be influenced by aspects of its intrinsic or extrinsic properties. Reminded of Semper's classification of variables, the use of dynamical systems methodology may provide some insight into how airflow interacts with building form at several scales — from the small to the urban.

Much debate about the usefulness of such information centers on the reliability of experimental methods, including those used by dynamical systems

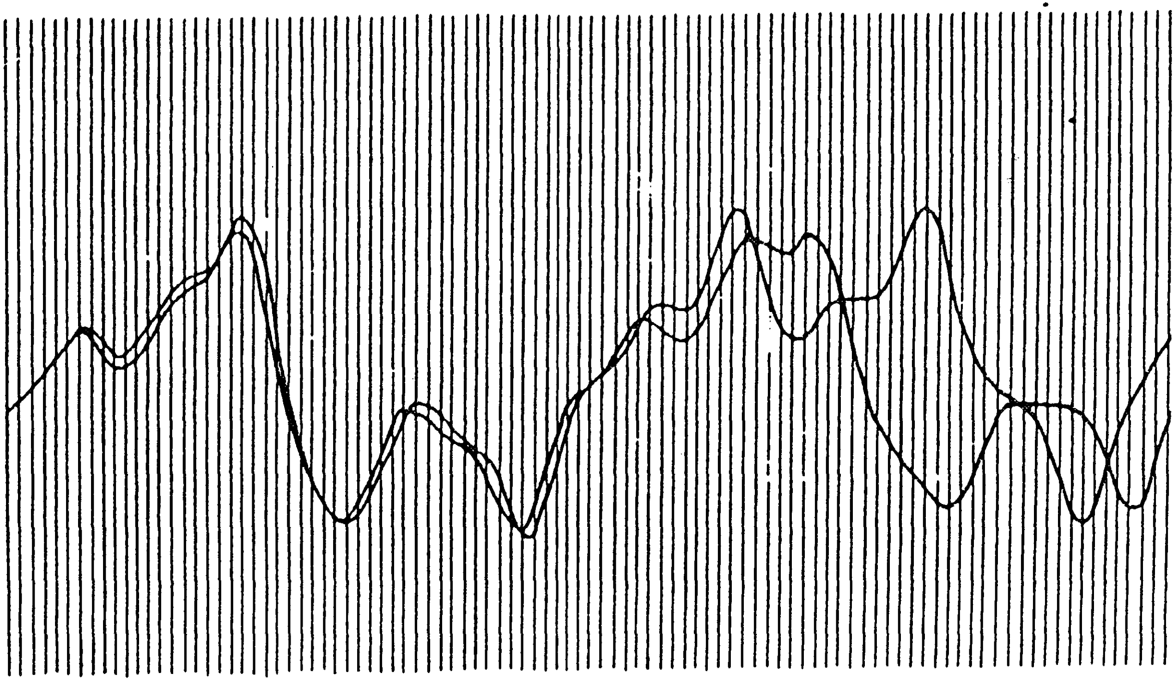


Fig. 40 Edward Lorenz, Diverging Weather Data in a Computer Simulation

analysts. The key point to establish is that phase plots exist not to predict but to understand behavior. In fact, many credit systems analysts with the fundamental knowledge needed to discredit attempts to predict physical behavior based on available data.

MIT Professor Edward Lorenz was among the first applied scientists to use the rudimentary computers of the 1960's in an effort to make headway in predicting weather based on available data sets. In the course of his experiments, he observed that an interrupted iteration of his computer program, with output at over 6 decimal points of accuracy, could not be exactly repeated with any exact similarity when restarted with nearly identical input. This observation became known as the "butterfly effect" owing to the notion that such experiments — and their real-life analogs — were highly sensitive to initial conditions, and the conjecture that a butterfly's wings could spawn a storm far from its flight path.

Though the rubrik is somewhat apocryphal, it serves to remind us that while prediction can be useful, the more important aspect of developing an appreciation for physical behavior is to lay bare the fundamental mechanisms of nature, and therby the essence of science, by explaining various kinds of behavior so that one could appropriately intervene in a complex natural system with a definitive building proposal.

The science of complexity is not a certain endeavor: as far as it has come, much remains to be understood about complex systems in order to make progress with models of integrated behavior, which in turn can inform attempts at integrated design. Current efforts

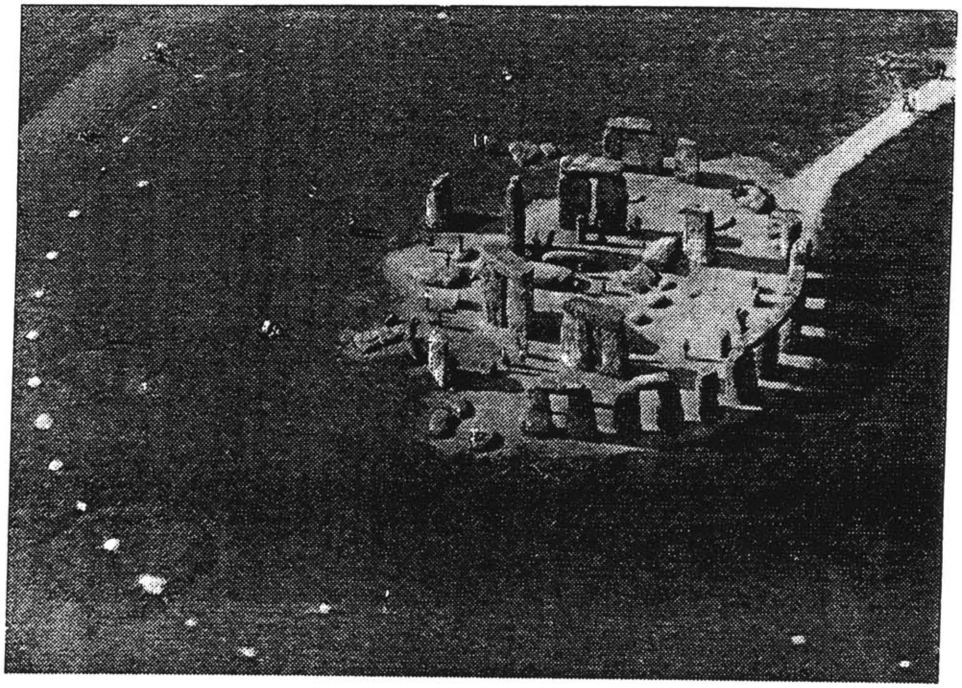


Fig. 41 Stonehenge, An Ancient Recognition of Dynamical Systems

in complexity is likened to the study of “thermodynamics before Carnot”, who developed the statements which would evolve into the second law of thermodynamics[8]. The ultimate aim of the science of complexity is a framework, or the principles of general pattern formation in non-equilibrium systems throughout the universe.

The direct benefit of work in this field is its capacity to assist the development of “effective energy”. Rather than limiting discussion to low- or zero-energy building proposals, the scientific framework provided by complexity theory would allow for the most carefully directed use of energy, whether in a building or possibly even a mechanical engine, since what is at stake in both cases is the physical flow of matter and the transfer of energy. In the end, there is a symbiosis at some level between the design of a building and the design of a product, just as there exists a self-similarity in the behavior of physical phenomena at different scales. What matters are the underlying principles.

This Thesis does not propose to define precisely how complexity theory can be subverted to comprise specific rules for design. Nature is too sophisticated for such an intrusion, just as the nineteenth century theoreticians discovered. By first recognizing that patterns do exist, and involve specific characteristics — the presence of multiple agencies (molecules or people), their capacity to adapt and respond with emergent behavior (flow patterns or stock market trades), exhibit self-organization (similarity at different scales: small / large, over days / weeks), and behav-

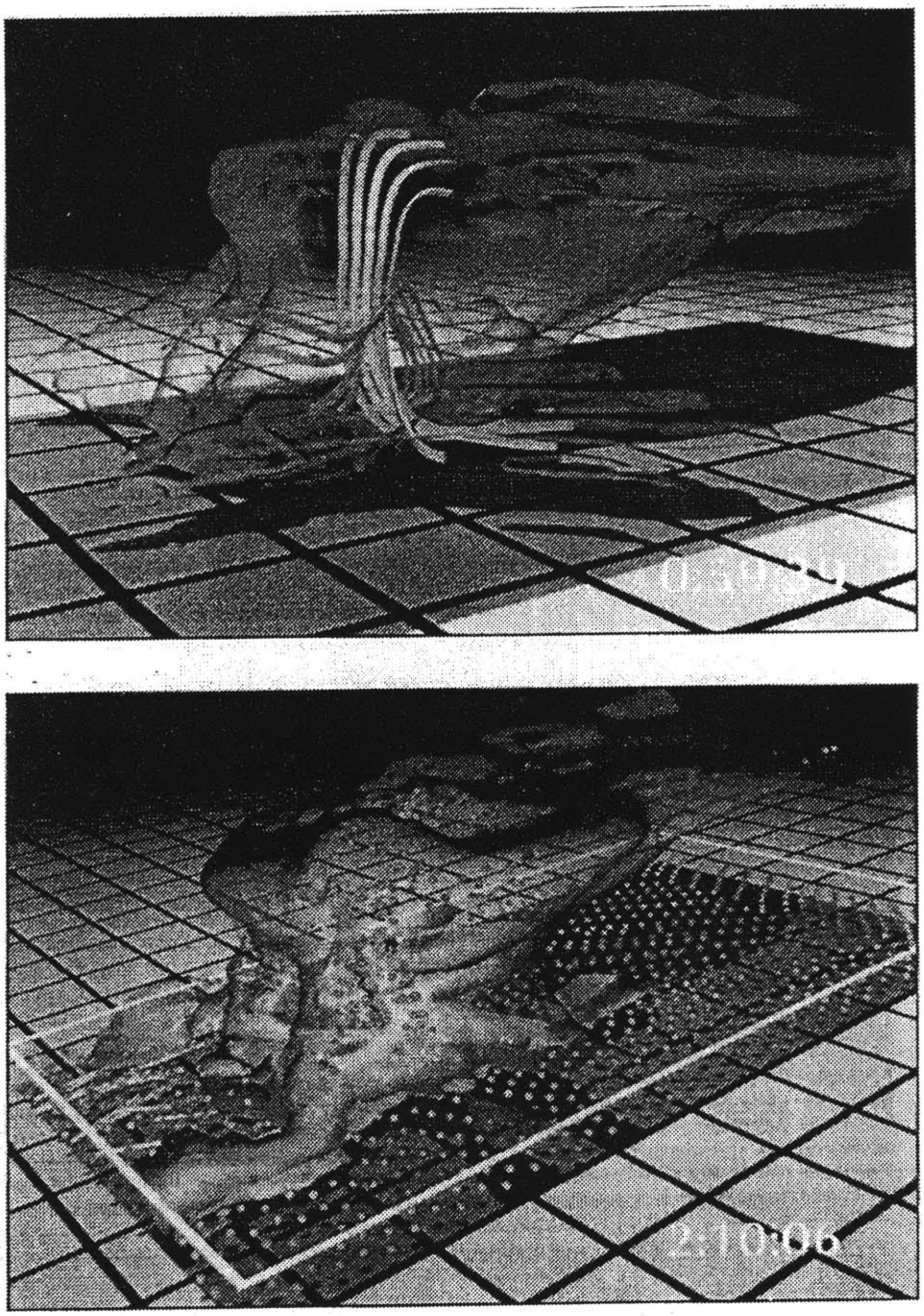


Fig. 42 Dynamic Computer Simulation of a Storm

ior which is sensitively dependent on initial conditions — the search for pattern can deeply inform the design of any building, especially one which supposes to interact within the principles of such pattern-making.

An interest in complexity is an expression of wonder and respect for the natural order which moves beyond surface metaphors and stylistic image tendencies and responds directly to physical behavior with tectonic integrity. By providing a contextual map of system dynamics and insights into the behavior of non-linear phenomena, it may be possible to re-address the question of "function" which Semper initiated nearly one hundred years ago. By promoting the consideration of an "empirical intuition", a full design matrix which includes formal, technical, social, and now physical variables, a bioclimatic approach may lead to more than efficient building form, it may lead to a more effective architecture with a knowledge base which responds to integrated criteria without headlining or marginalizing the notion of symbolic integrity, or "truth" in design, as postulated by pre-Enlightenment theorists.

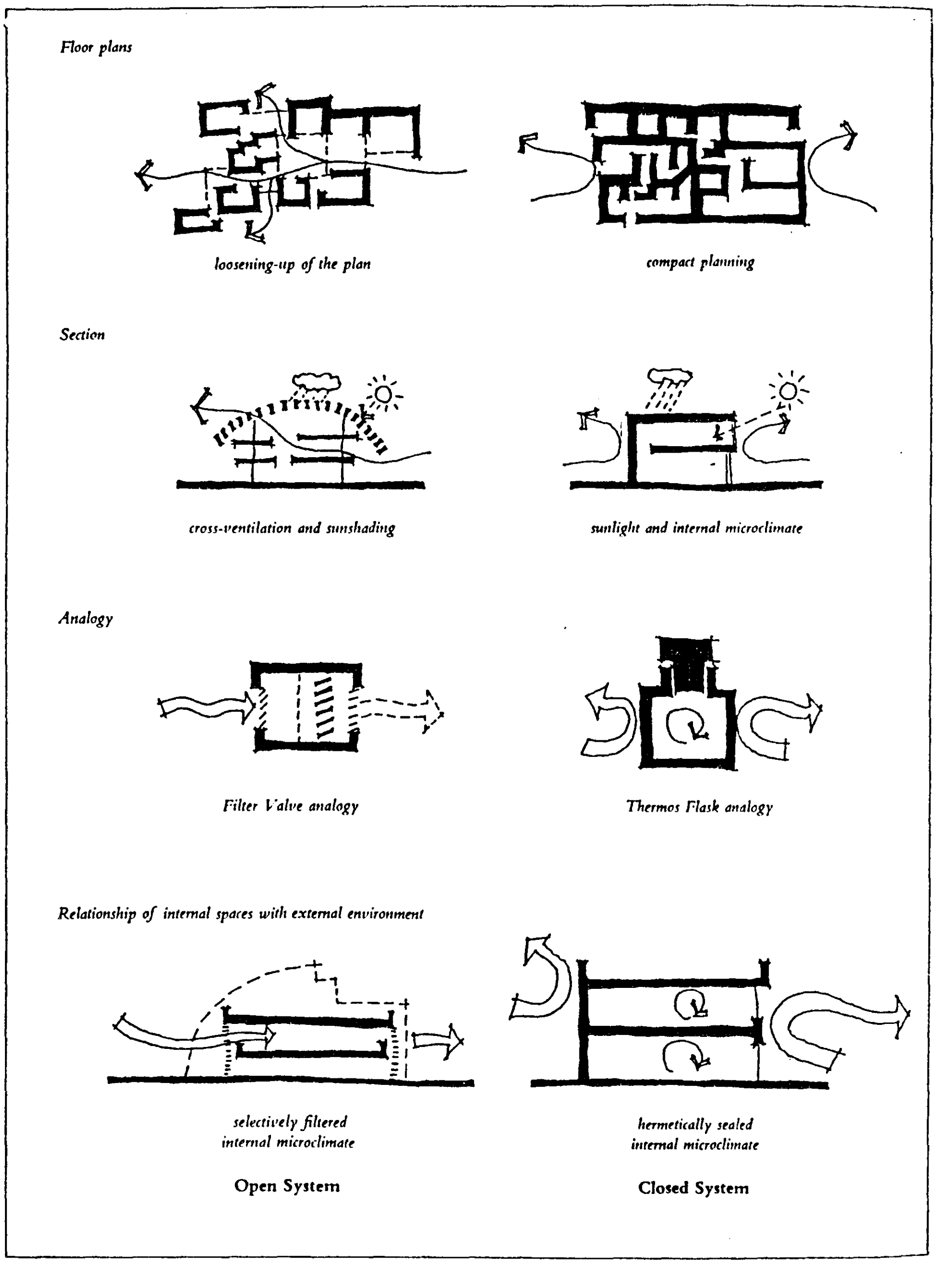


Fig. 43 Ken Yeang: Rethinking the Environmental Filter, Building Analogies

Precedents

Although the design precedents shown here are not explicitly derived from scientific theories alluded to in earlier chapters, they do respond in different ways to a mandate for integrated approach to the tall building typology.

As a measure of formal antecedent, a basecase deep plan and sealed skin building type is described in the following chapter in order to represent a default, high-energy solution to the design of an office environment.

While the design precedents exhibit bioclimatic characteristics, it could be said that the deep-plan typology is rather anti-climatic in its depreciation of the sensibilities required in dwelling with the natural environment.

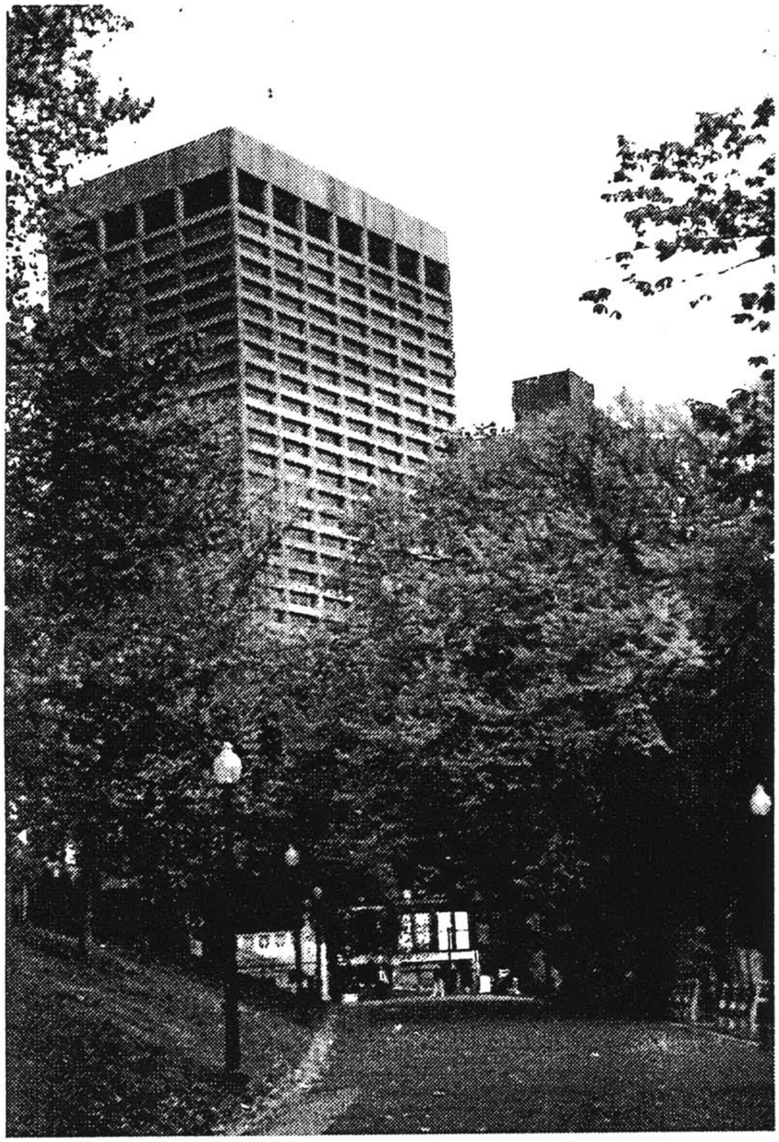


Fig. 44 Typical Boston Office Building, with identical facades despite different loads

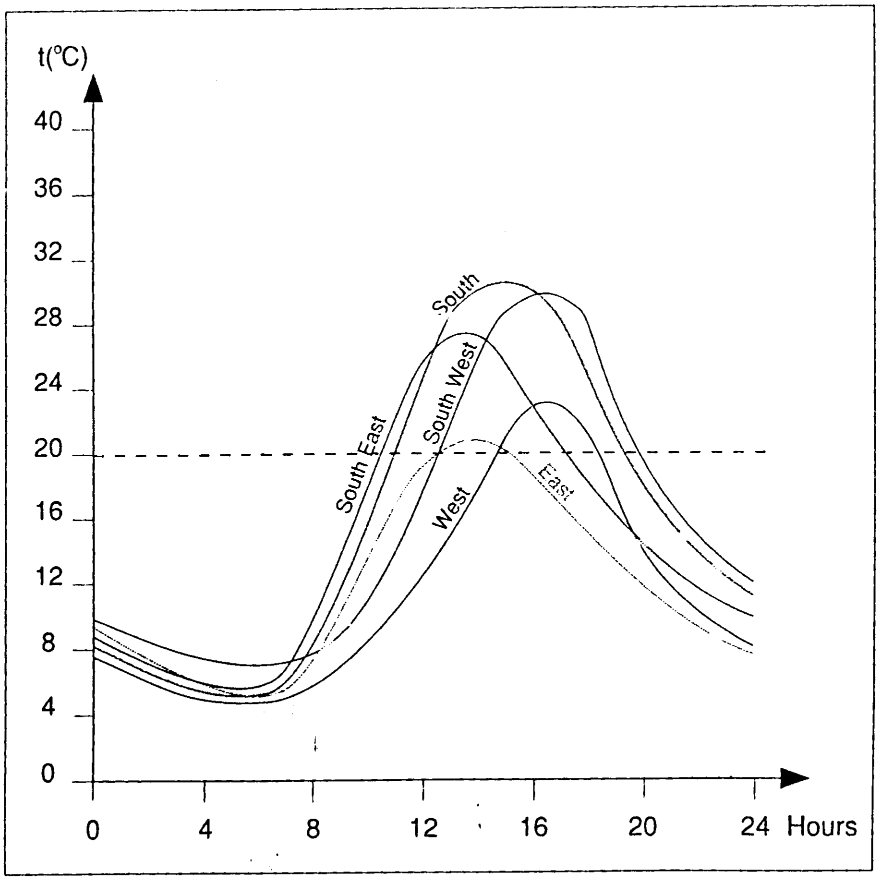
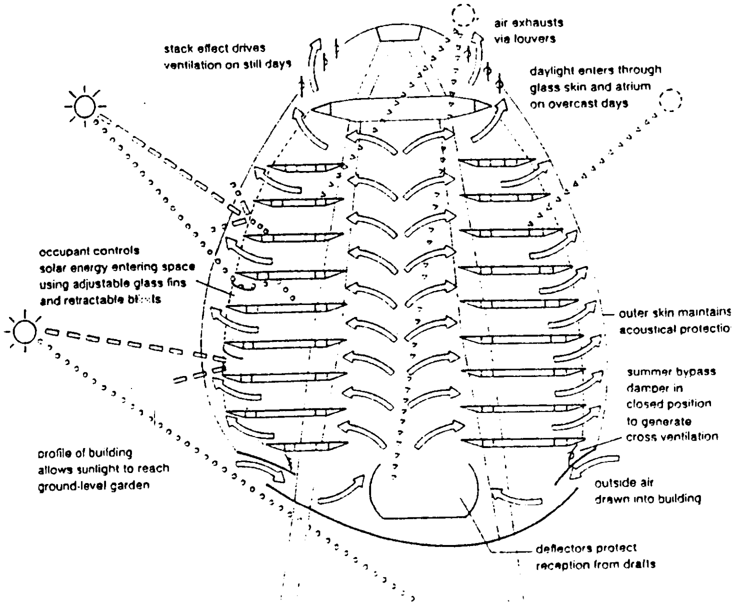
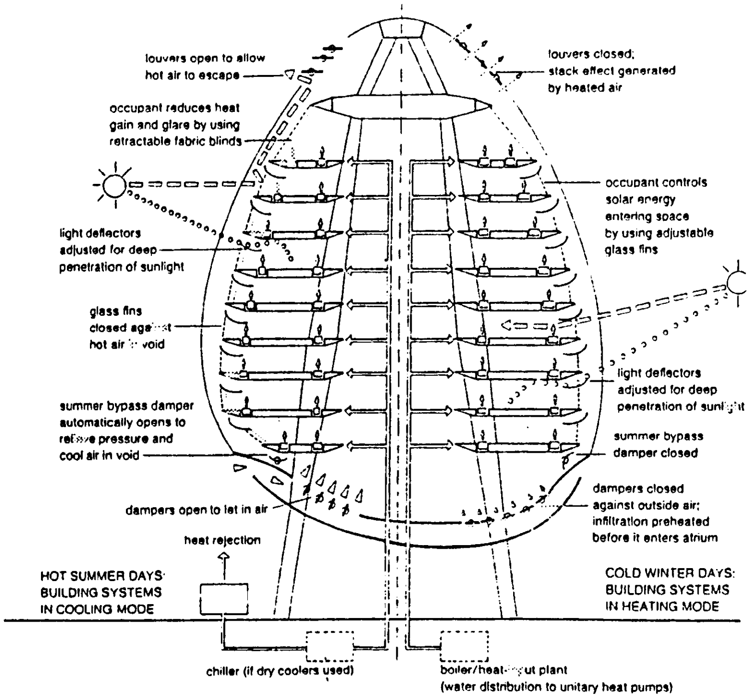


Fig. 45 Load Conditions by Elevation Orientation



DAYLIGHT AND VENTILATION-NORMAL CONDITIONS



DAYLIGHT AND VENTILATION-EXTREME CONDITIONS

Fig. 46 Future Systems, Green Building, Sectional Diagrams

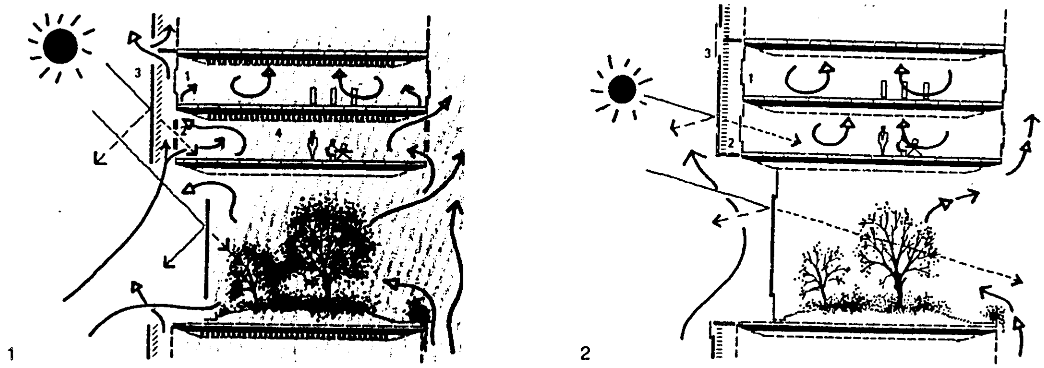
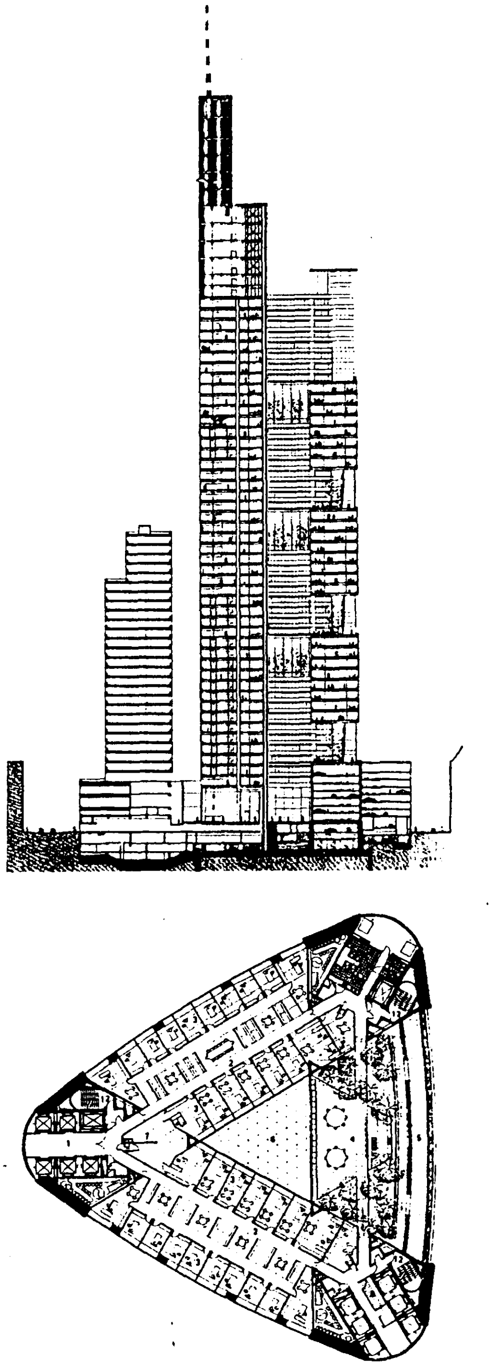


Fig. 47 Norman Foster, Commerzbank, Frankfurt, Sectional Studies



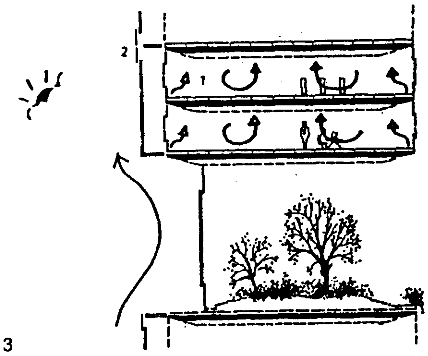


Fig. 48 Norman Foster, Commerzbank, Frankfurt, Plan and Section

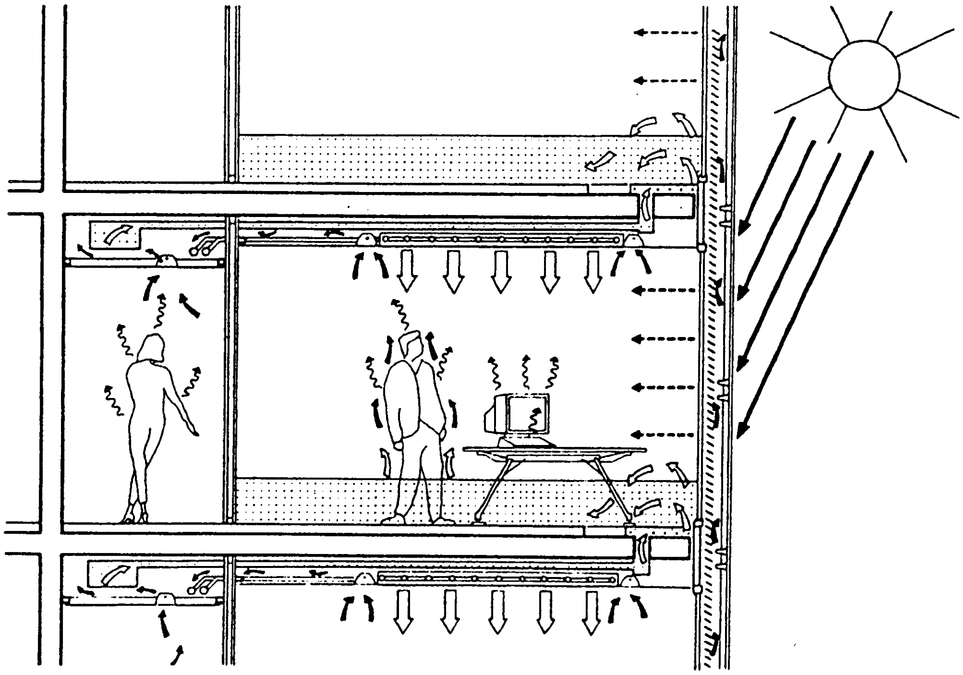


Fig. 49 Norman Foster, Duisbeg Business Centre, Sectional Study

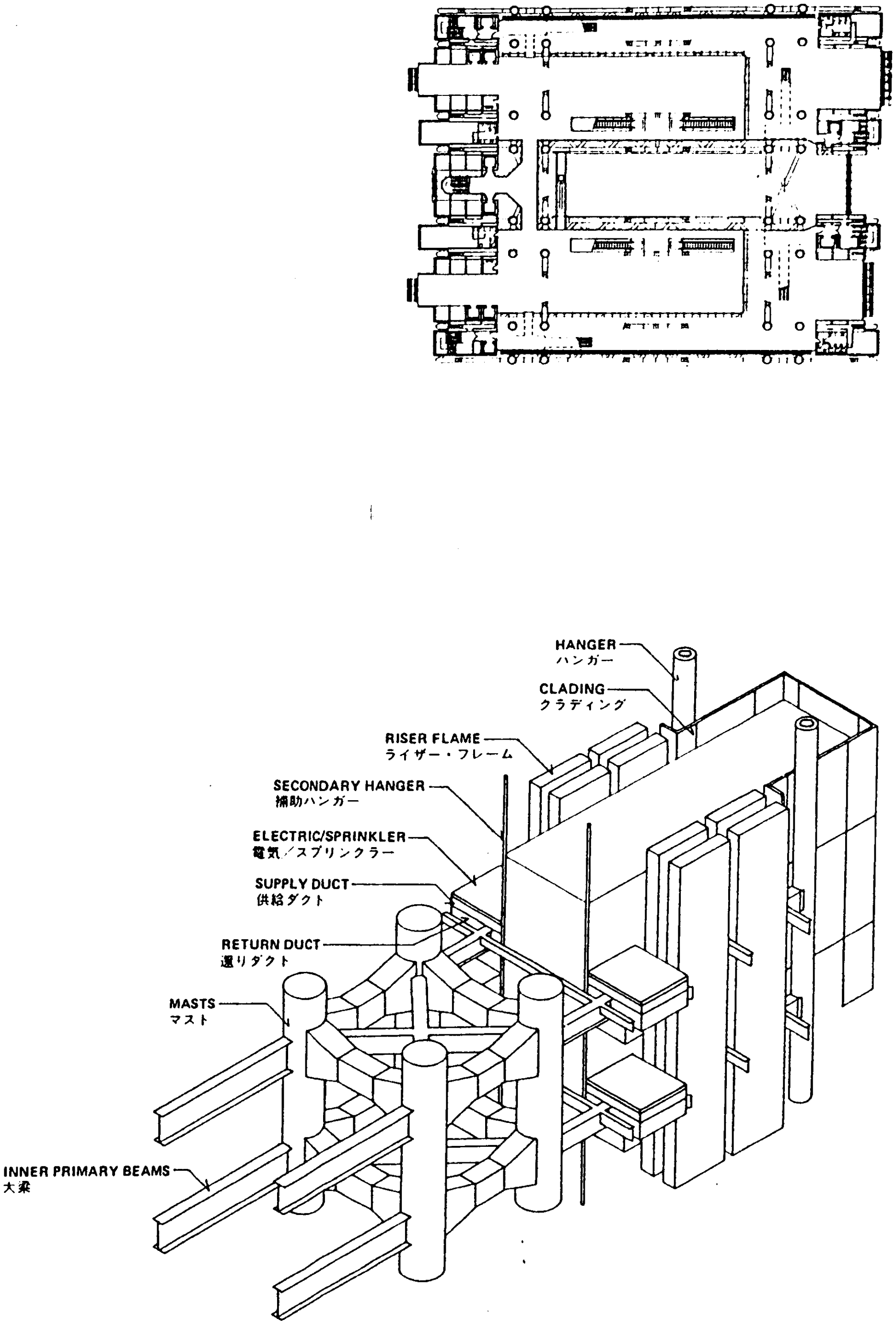


Fig. 50 Norman Foster, Honk Kong Bank, Systems Integration, Plan

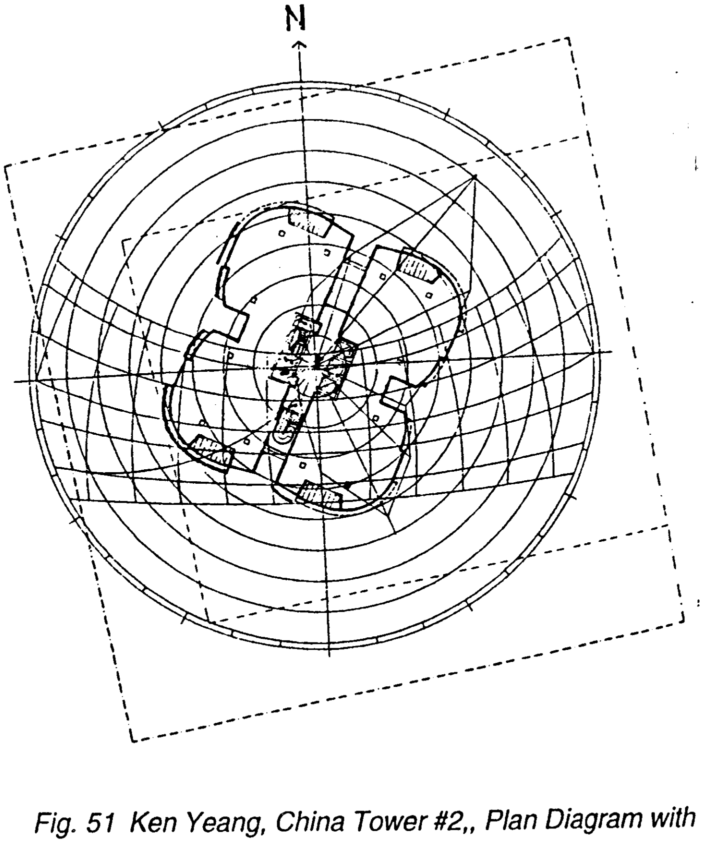


Fig. 51 Ken Yeang, China Tower #2,, Plan Diagram with Sunpath

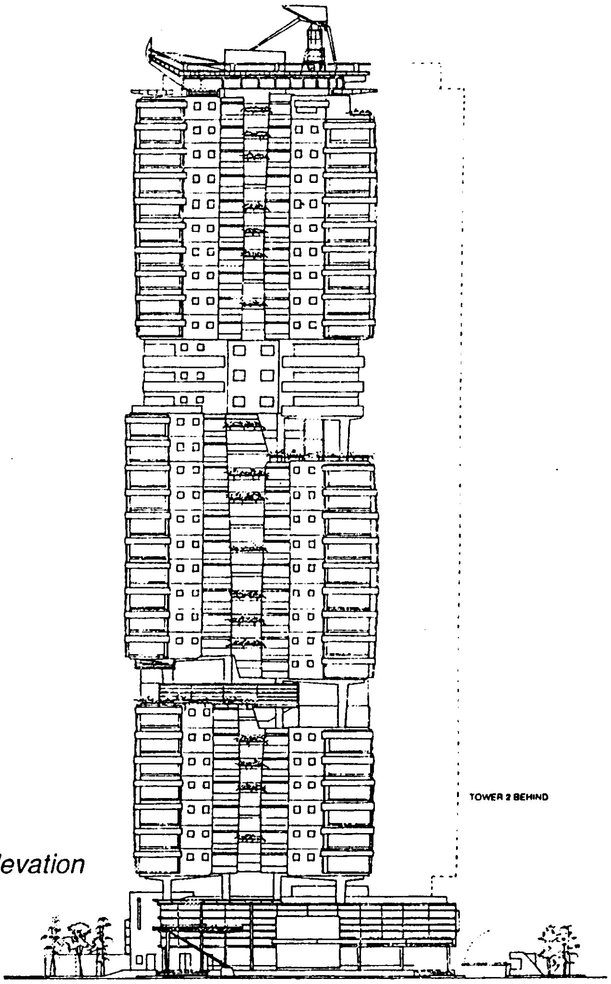


Fig. 52 Ken Yeang, China Tower #2, Elevation

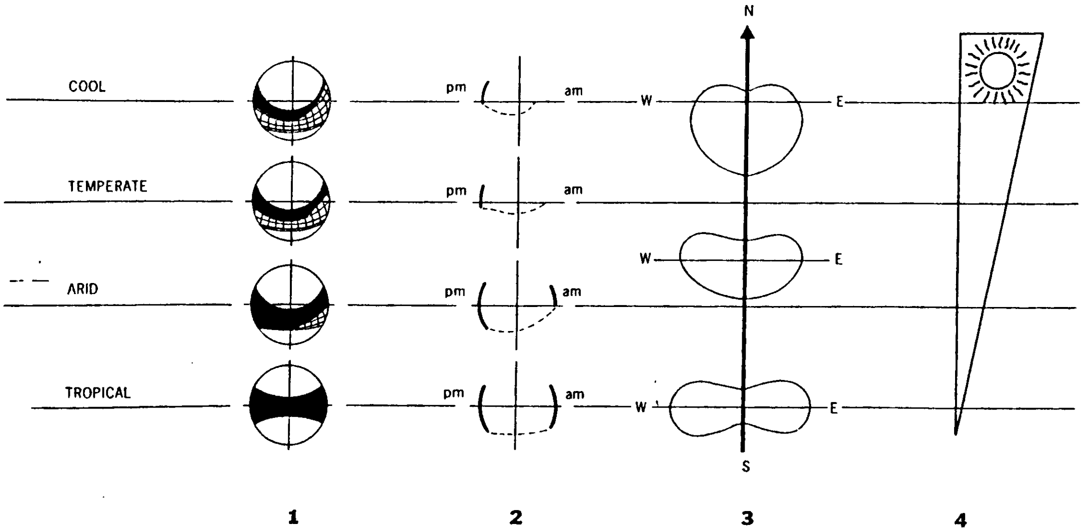


Fig. 53 Ken Yeang, Bioclimatic Strategies for Dalighting

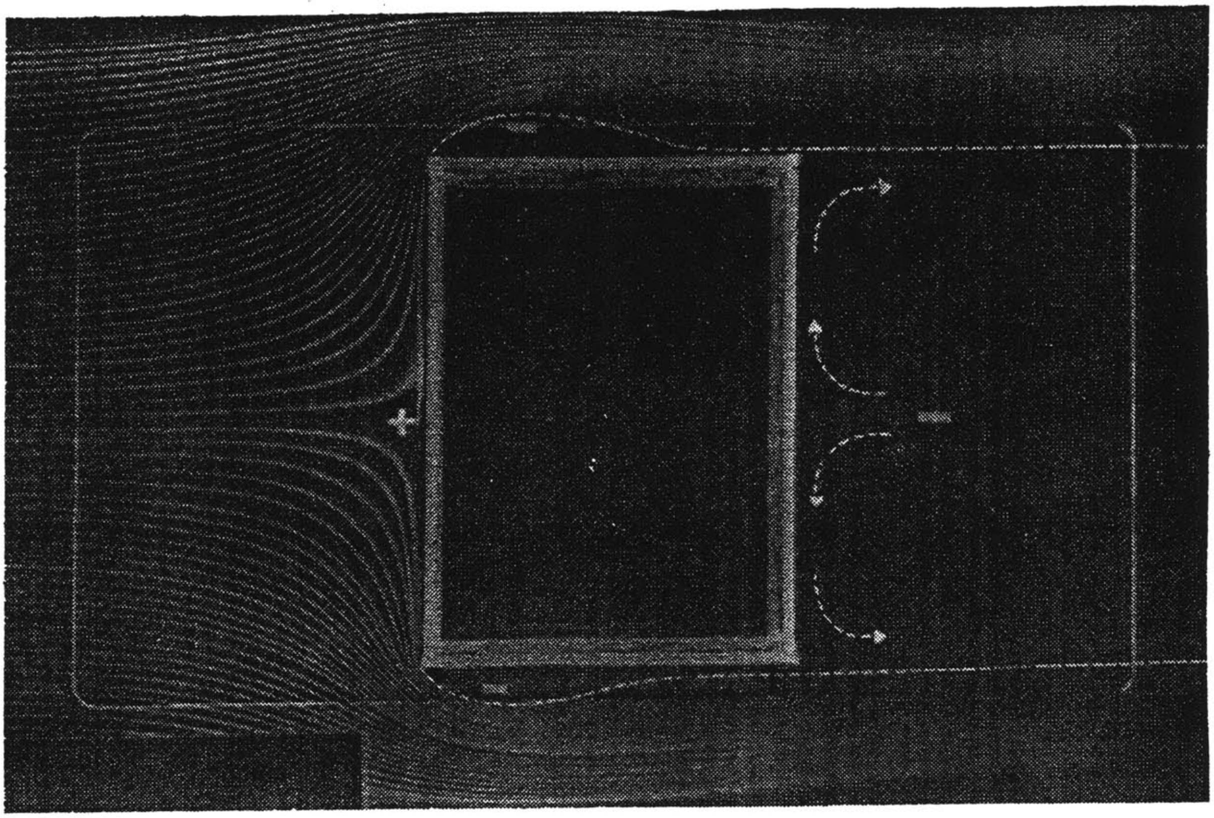


Fig. 54 Airflow Past a Rectangular Building, Wind Tunnel Test

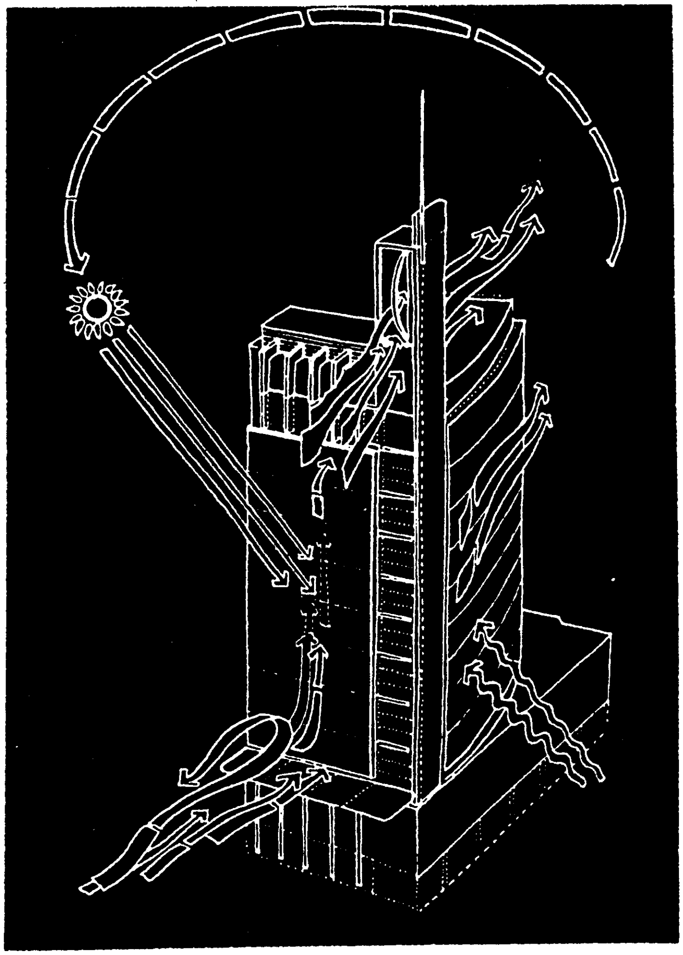


Fig. 55 Battle McCarthy, Centre Rogier,
Environmental Interactions

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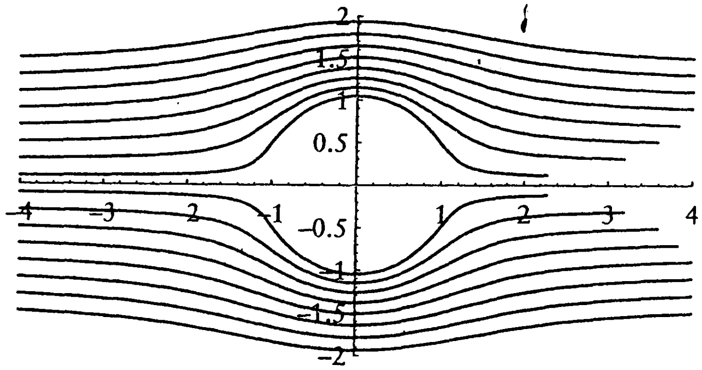
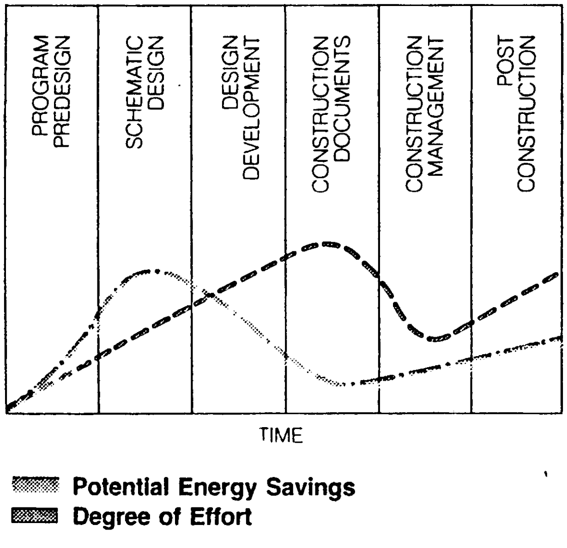


Fig. 56 Fluid Flow Past A Cylinder, Computer Simulation

Fig. 57 Richard Rogers, Tomigaya Project, Diagram and Airflow Studies

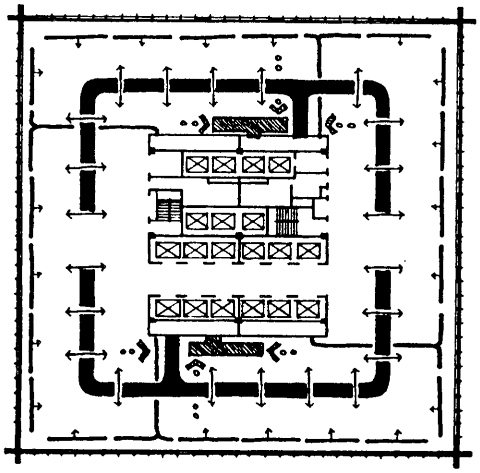
> " How many times in the course of my life had I been disappointed by reality because, at the time I was observing it, my imagination -- the only organ with which I could enjoy beauty -- was not able to function, by virtue of the inexorable law which decrees that only that which is absent can be imagined."
>
> -- *Marcel Proust*
> On Learning and Meaning, in
> Minsky, The Society of Mind

LEVEL OF ENERGY SAVINGS THAT CAN BE ACHIEVED AT VARIOUS STAGES IN THE PROJECT DELIVERY PROCESS.



Source: AIA, Energy in Design: Techniques, 1982, Washington, D.C.

Fig. 58 Potential Energy Savings

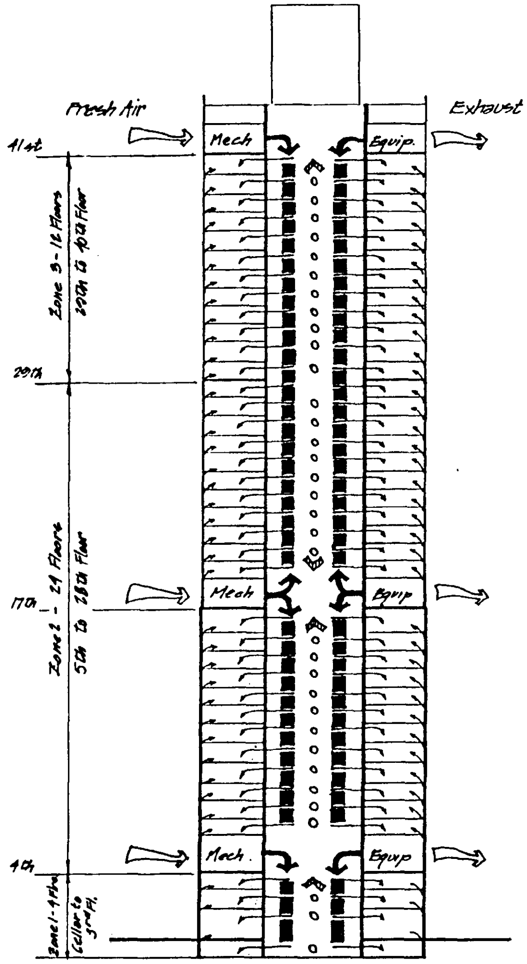


Interior spaces are supplied from two shafts located on opposite sides of the core.

Return air is through the ceiling planum to two return shafts.

Exterior induction units are supplied from four high-speed ducts, one for each facade.

Fig. 59 Typical Deep Office Plan, showing Mechanical Core



BOSTON COMPANY
Mechanical Section

Fig. 60 Typical Center Core Section, showing Mechanical Spaces

CITY ANALYSES 1993

Boston, MA

ALL DOWNTOWN

	TOTAL BUILDING RENTABLE AREA					TOTAL OFFICE RENTABLE AREA			
	52 BLDS	16,228,859 SQ. FT.				15,480,046 SQ. FT.			
	# BLDS	DOLLARS/SQ. FT.		MID RANGE		DOLLARS/SQ. FT.		MID RANGE	
INCOME		AVG	MEDIAN	LOW	HIGH	AVG	MEDIAN	LOW	HIGH
OFFICE AREA	52					22.77	20.72	15.25	26.54
RETAIL AREA	35	19.71	20.28	10.65	30.44				
OTHER AREA	9	6.17	6.57	5.67	9.49				
TOTAL RENT	52	22.44	20.49	15.68	26.29				
NET PARKING INC	29	1.46	1.27	.67	1.84				
MISCELLANEOUS	39	.41	.08	.04	.15				
TOTAL INCOME	52	23.88	20.99	16.31	26.29				
EXPENSE									
CLEANING	51	1.04	1.03	.89	1.13	1.08	1.08	.96	1.19
REPAIR/MAINT	52	1.50	1.19	.98	1.66	1.55	1.28	1.04	1.73
UTILITIES	52	2.11	1.91	1.32	2.53	2.17	1.98	1.37	2.53
RDS/GDS/SEC	52	.50	.52	.41	.65	.53	.54	.43	.70
ADMINISTRATIVE	50	1.05	1.04	.81	1.40	1.10	1.11	.94	1.47
TOTAL OPER EXP	49	6.19	6.03	5.55	6.93	6.50	6.29	5.89	7.35
FIXED EXPENSES	52	4.49	3.83	3.00	4.62	4.71	4.18	3.38	4.83
TOTAL OPER+FIX	49	10.73	10.21	8.59	11.29	11.26	10.48	9.65	11.83
LEASING EXP	42	1.62	.63	.17	1.74				
TOTAL PAYROLL	49	.88	.77	.60	1.09				
TOTAL CONTRACT	43	2.23	2.16	1.73	2.52				

Fig. 61 BOMA Experience Exchange Report

1992 construction cost ($86.45/sq ft excl. land, fin., & approvals) of a typical new U.S. 140,000-sq-ft, 15-story office building

of which space cooling/air handling eqt. = $7.62 (8.8%),
total design fees = $4.91 (5.7%),
SC&AH eng. < $0.50 (0.6%)

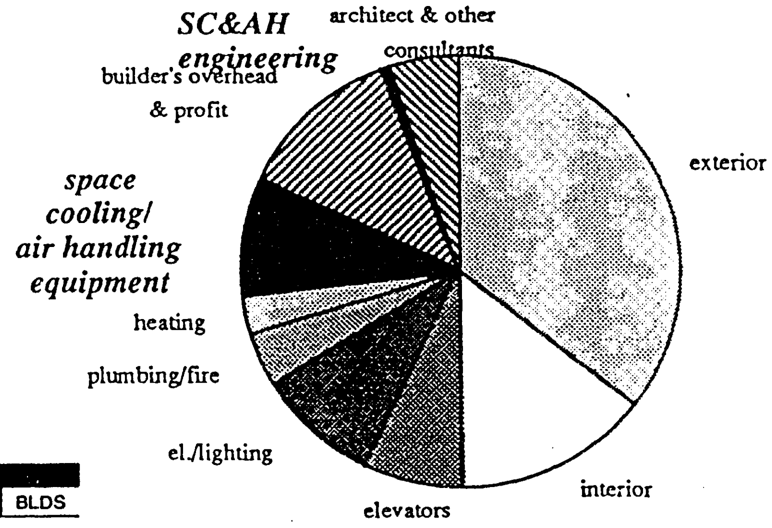


Fig. 63 Construction Cost Breakdown

OCCUPANCY INFO.	AVERAGE	BLDS
SQFT/OFFICE TENANT	12,272	46
SQFT/RETAIL TENANT	3150	35
SQFT/OFFICE WORKER	252	36
SQFT/MAINT STAFF	92,274	37
OFFICE OCCUPANCY (%)	86.4	52
RETAIL OCCUPANCY (%)	78.4	35
YR-END RENT ($)	25.33	40
NET PRKNG INC/STALL ($)	2633	25
PARKING RATIO (SF)	2458	22
RENTABLE/GROSS SQFT	.89	48

Fig. 62 BOMA Experience Exchange Report (cont'd)

% total summer peak demand due to:	**Contributing factors:**
HVAC (47%)	Outside ventilation air required by codes is high in temperature and humidity Heat gain through transmission Maximum solar heat gain Maximum internal gains (lights, equipment, people) Normal room temperature and humidity Accumulated heat, possibly from shut down over weekend Efficiency of system is low
Lights (40%)	Greatest-expected number of lighting fixtures switched on
Elevators (7%)	Maximum use of elevators as people leave and enter building Efficiency of system
Hot water (4%)	Supply water temperatures maintained as usual; water heater may have come on during peak
Other (2%)	Normal operations Efficiency of system

Fig. 64 Factors Contributing to Peak Electrical Demand

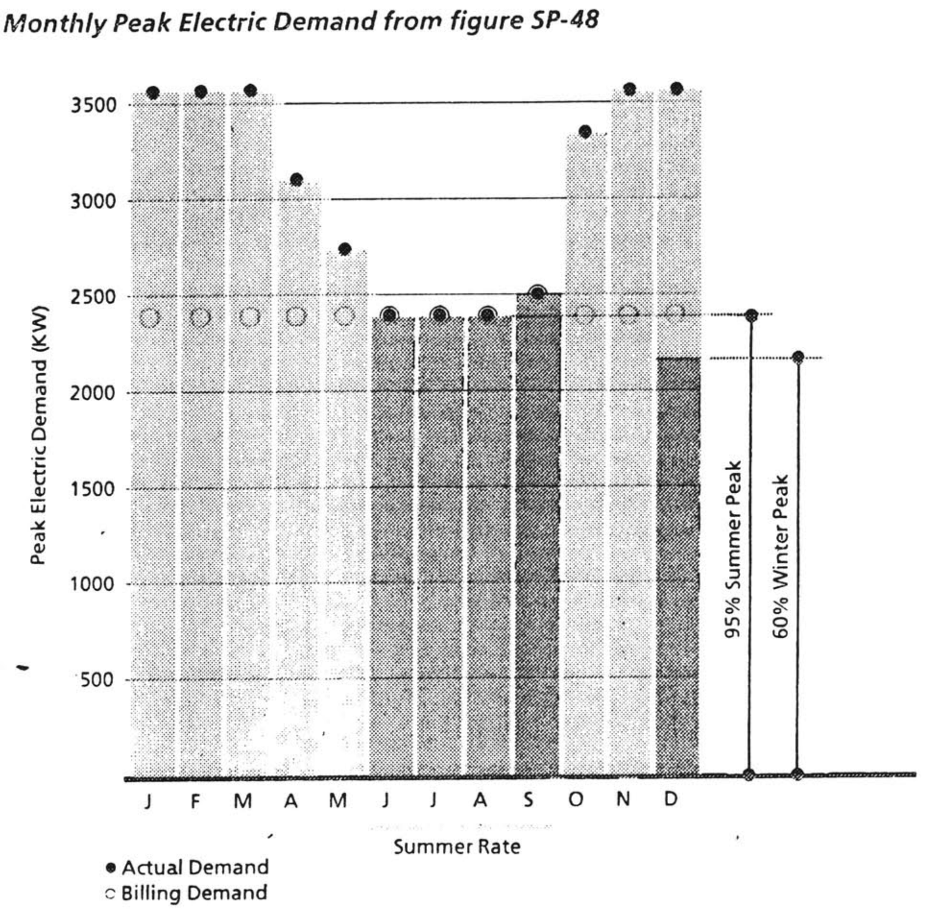
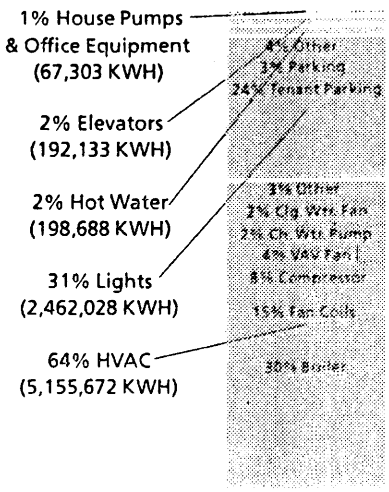


Fig. 65 Monthly Peak Electrical Demand

Average Annual Electric Consumption Breakdown from figure SP-48



Item	% Total	
HVAC		
Boiler	30%	
Fan Coils	15%	
Compressor	8%	
VAV Fan	4%	**64%**
Ch. Wtr. Pump	2%	
Cl. Twr. Fan	2%	
Other HVAC	3%	
Lights		
Tenant Spaces	24%	
Parking	3%	**31%**
Other Lights	4%	
Hot Water	2%	
Elevators	2%	**5%**
Rest	1%	

Total Consumption/Yr = 8,075,824 KWH/YR
= 27,562,787 MBTU/Yr = 86 MBTU/gross sq. ft./yr.

Fig. 66 Electric Consumption Breakdown

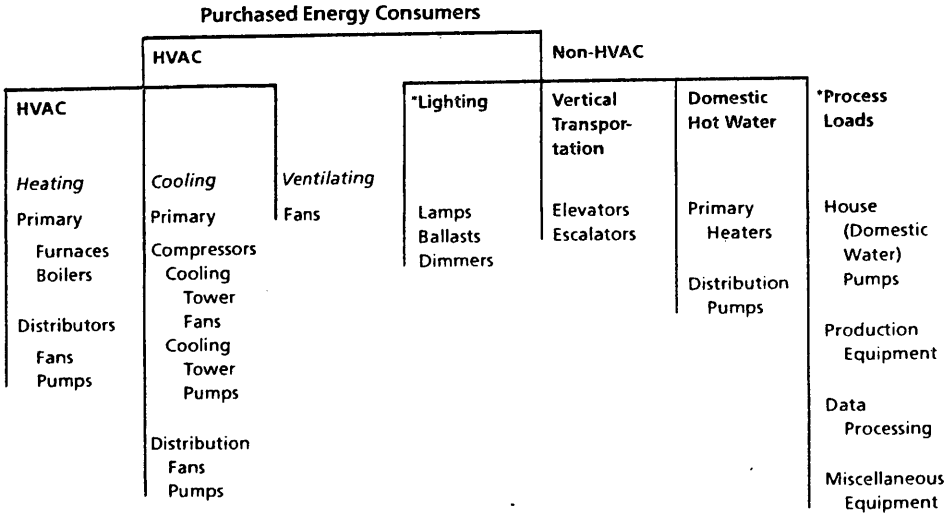


Fig. 67 Sources of Electrical Loads in Buildings

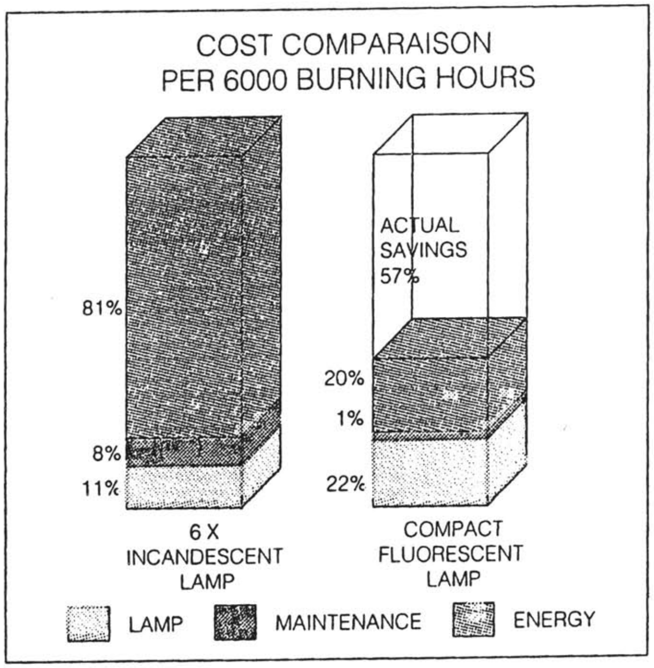


Fig. 68 Lighting Costs

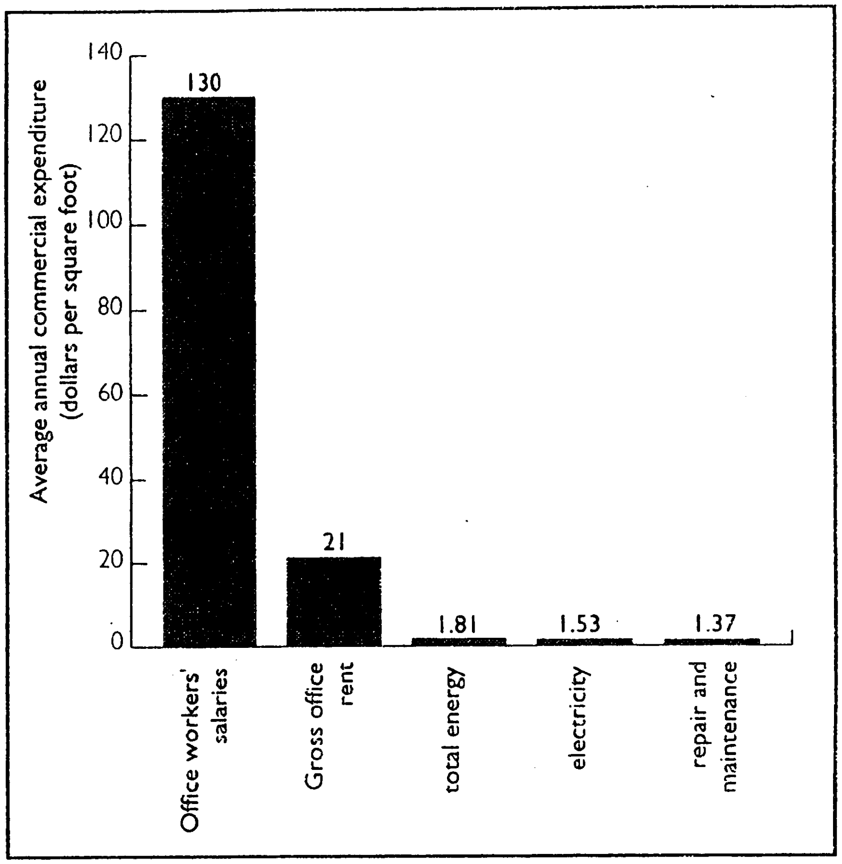
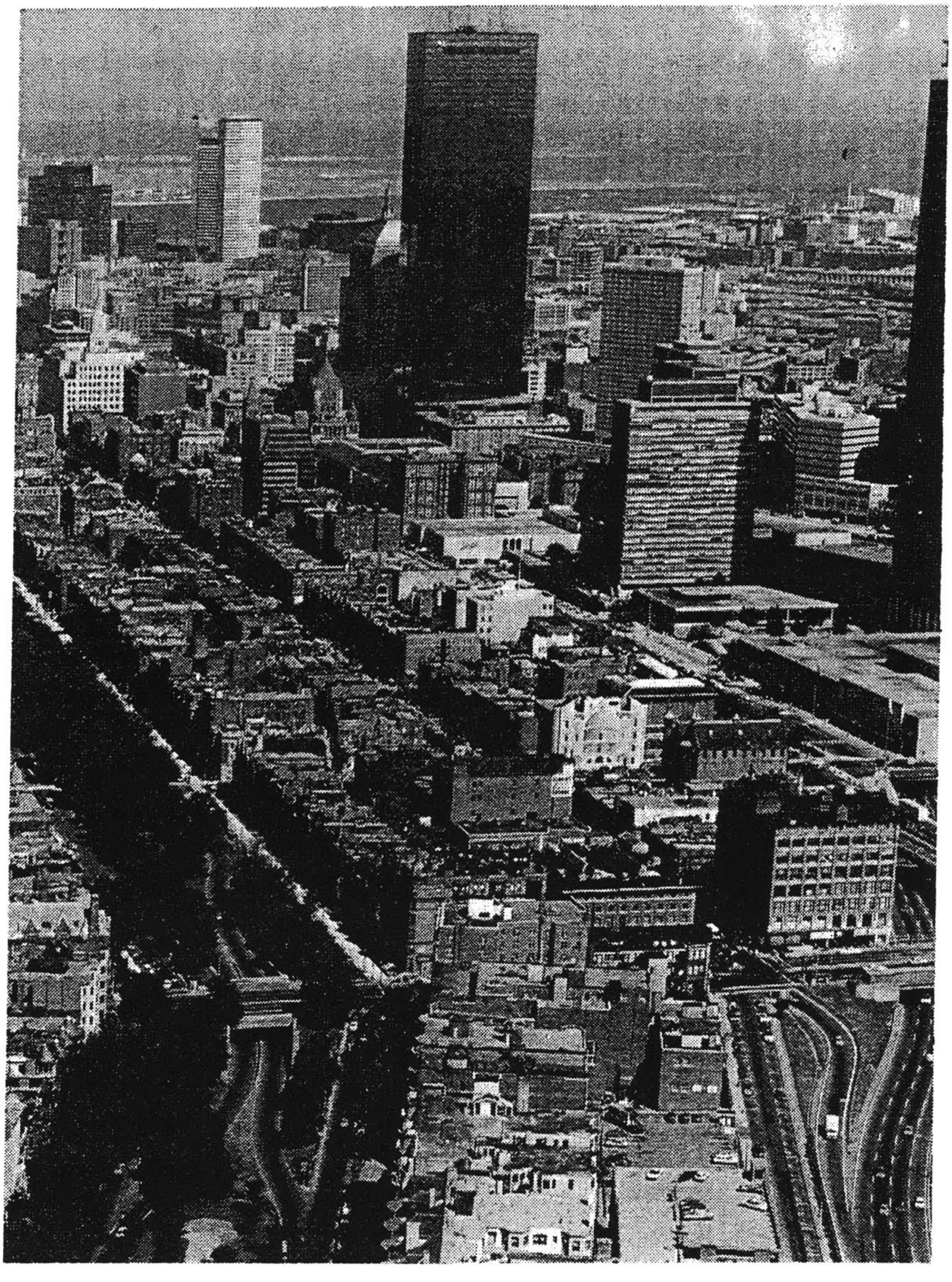


Fig. 69 Building Tenant Costs per Square Foot /Year

Fig. 70 Boston Skyline looking east towards the common



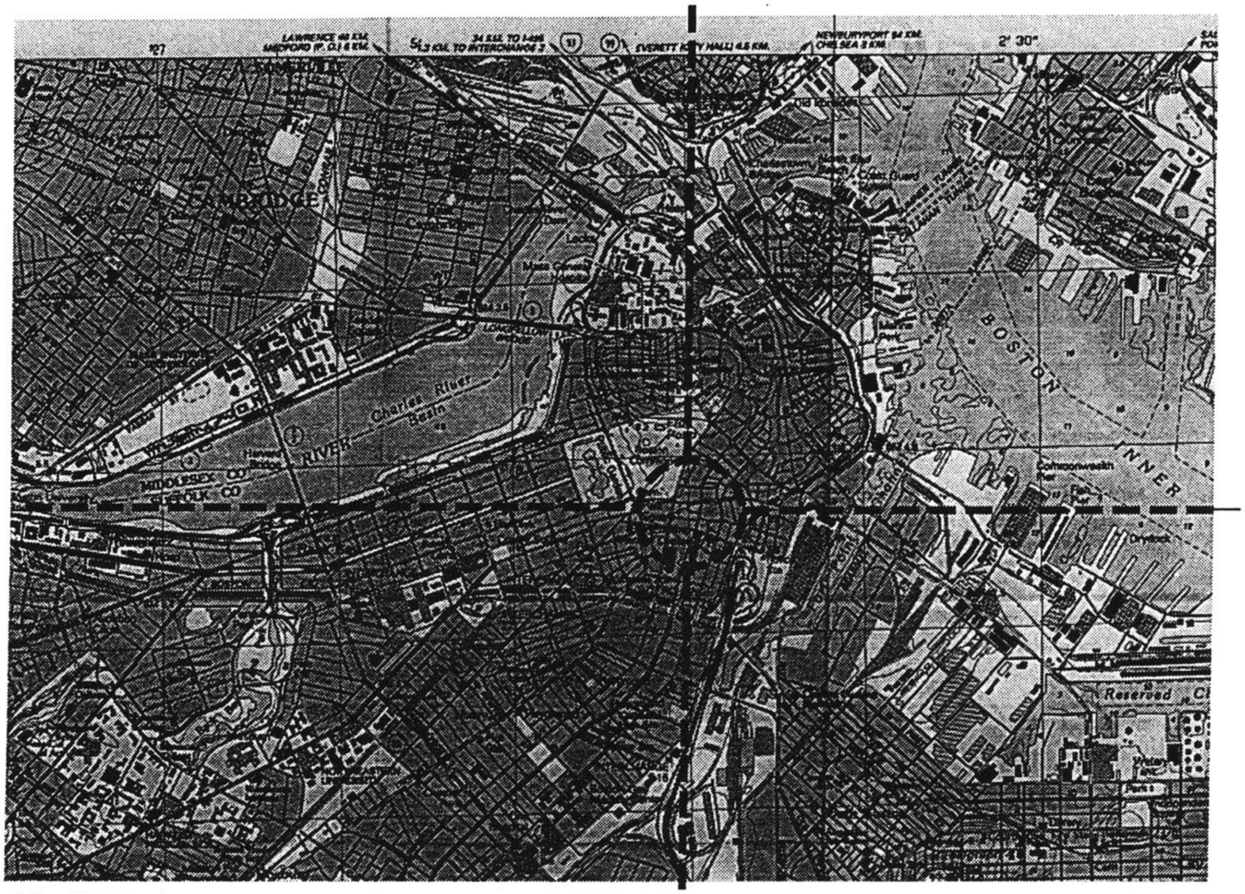


Fig. 71 Boston

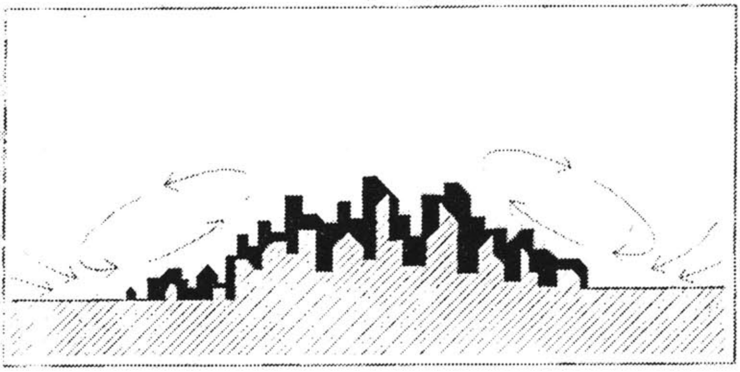


Fig. 72 Turbulent Windflow in an Urban Environment

Case Study Design Proposal

A Multi-Use Commercial Office Building

The Hinge Block, Boston, MA

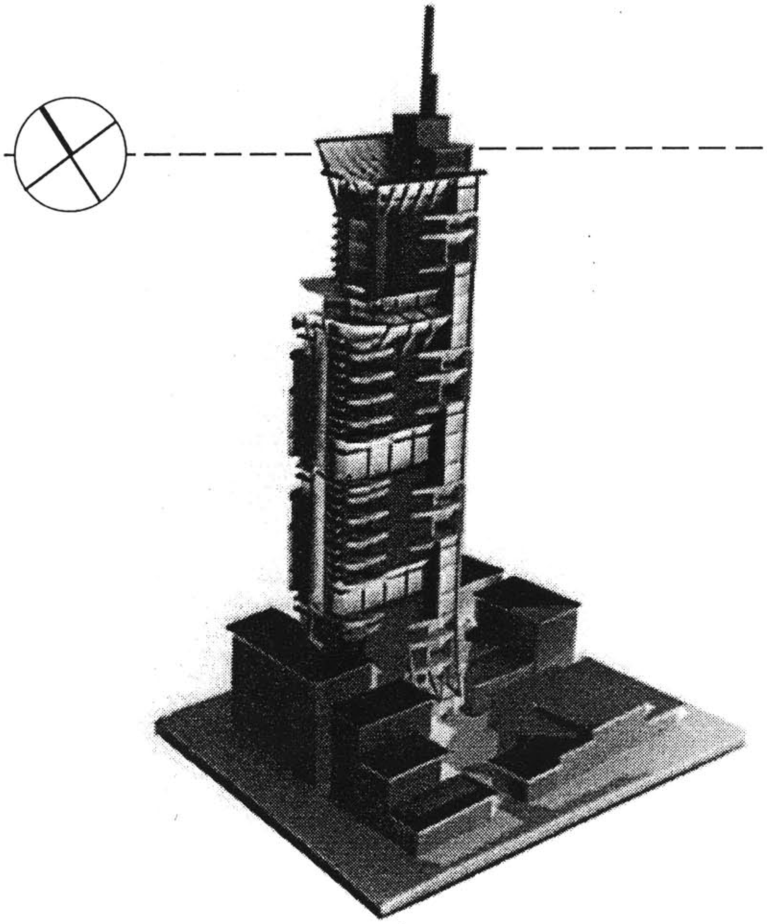


Fig. 73 View of model from Southwest

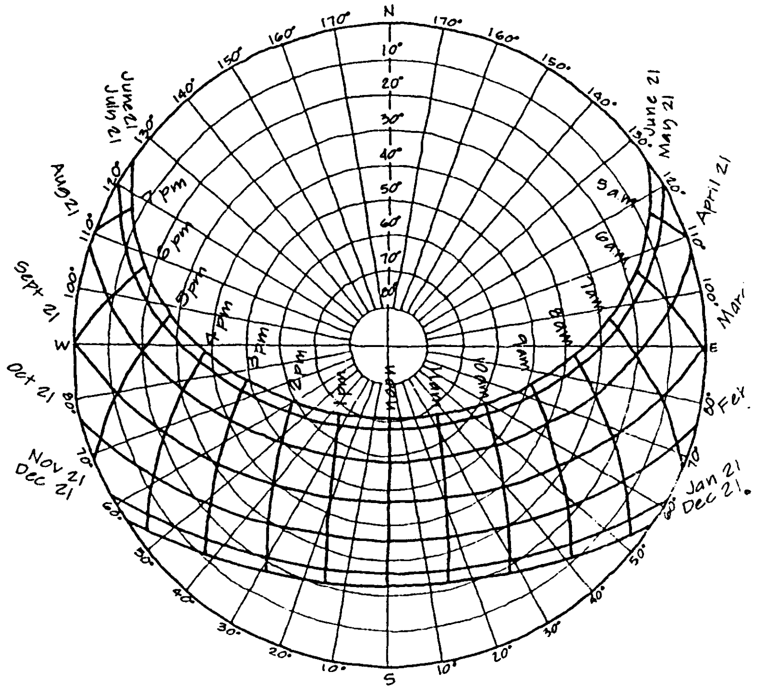
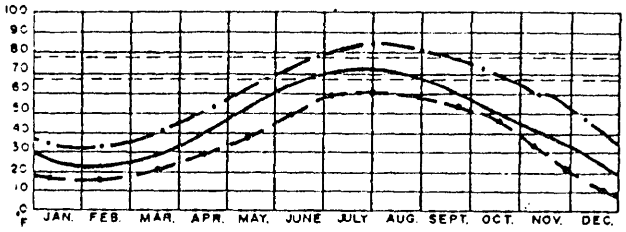
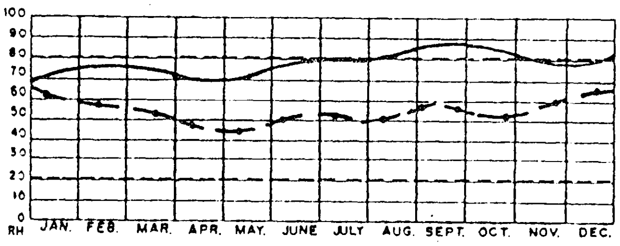


Fig. 74 Sun Path Diagram @ 44N Latitude

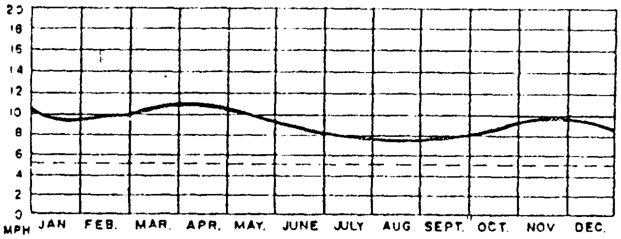
Temperature



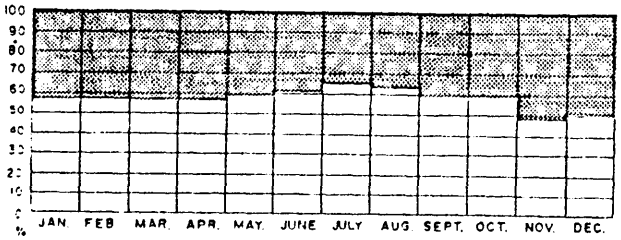
Relative Humidity



Wind Speed



Sunshine



Degree Days

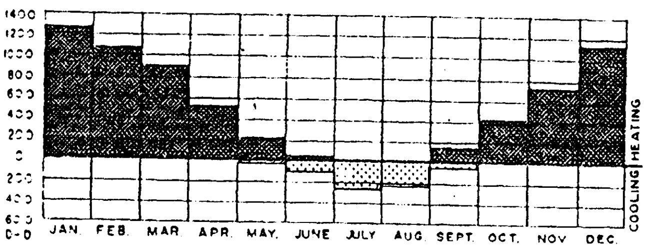


Fig. 75 Climate Data

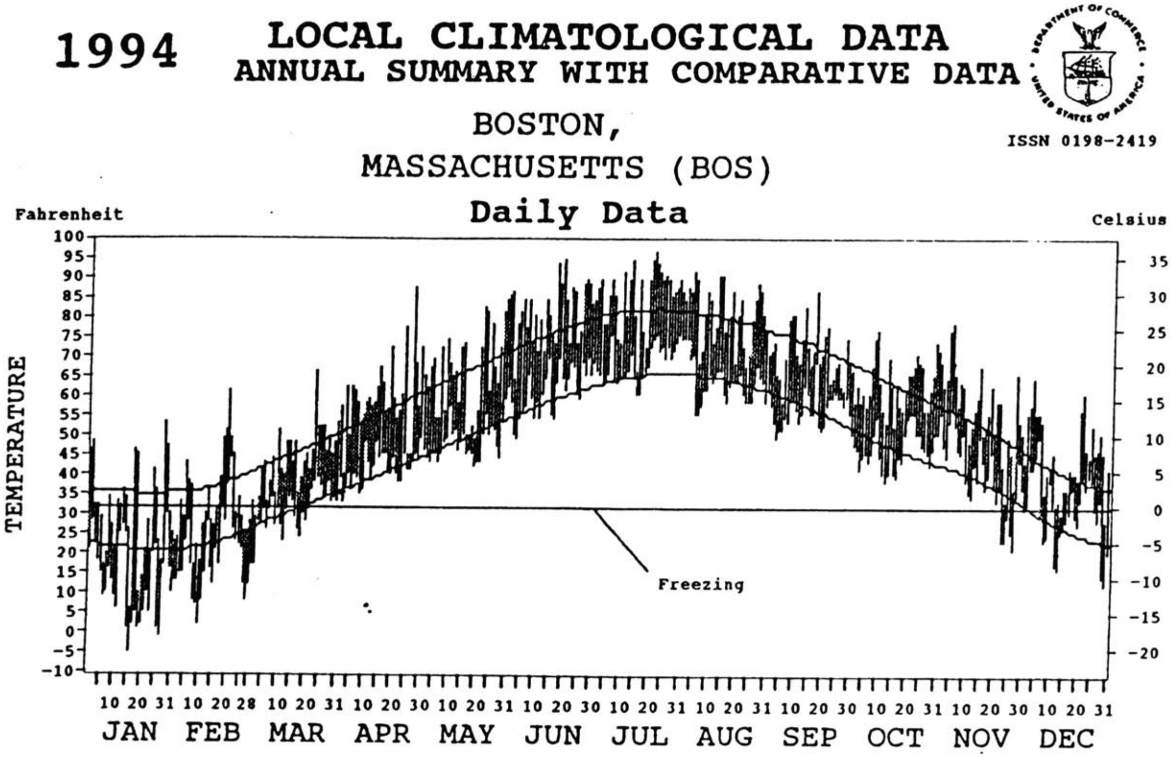


Fig. 76 NOAA Temperature Profile for Boston

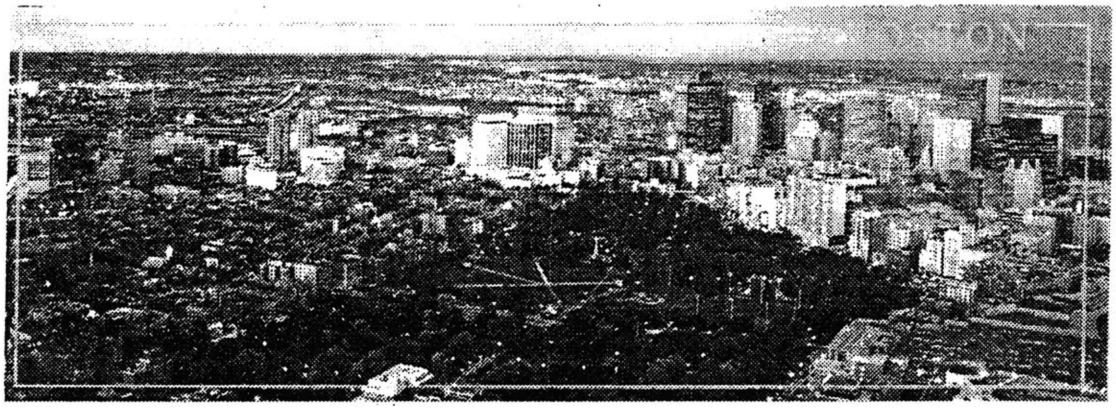


Fig. 77 Boston Skyline

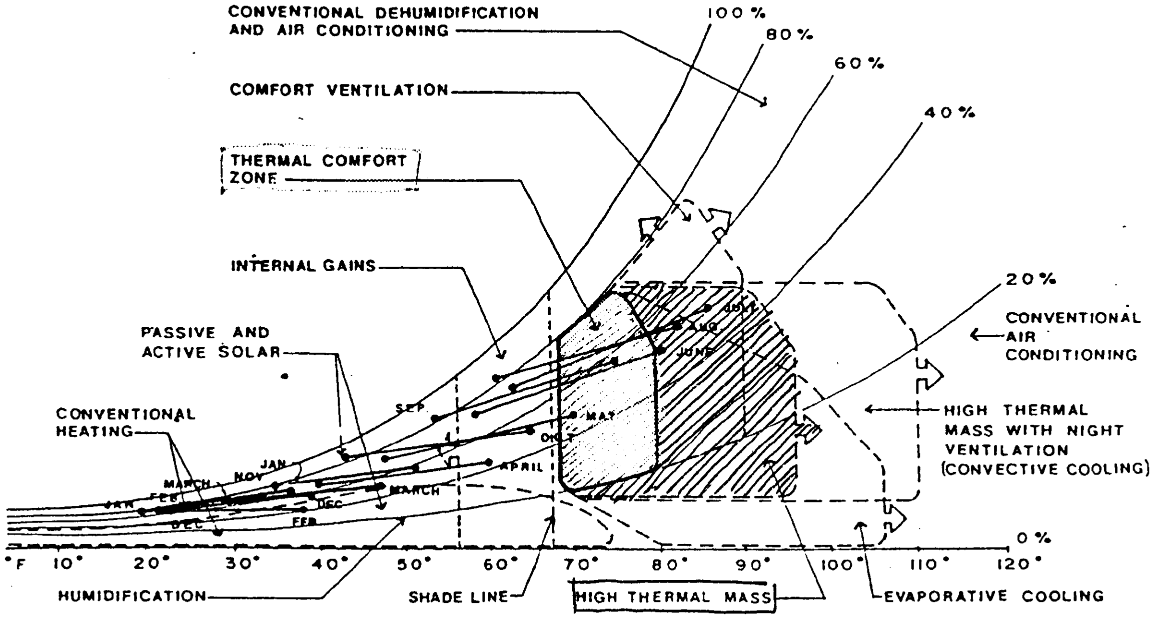
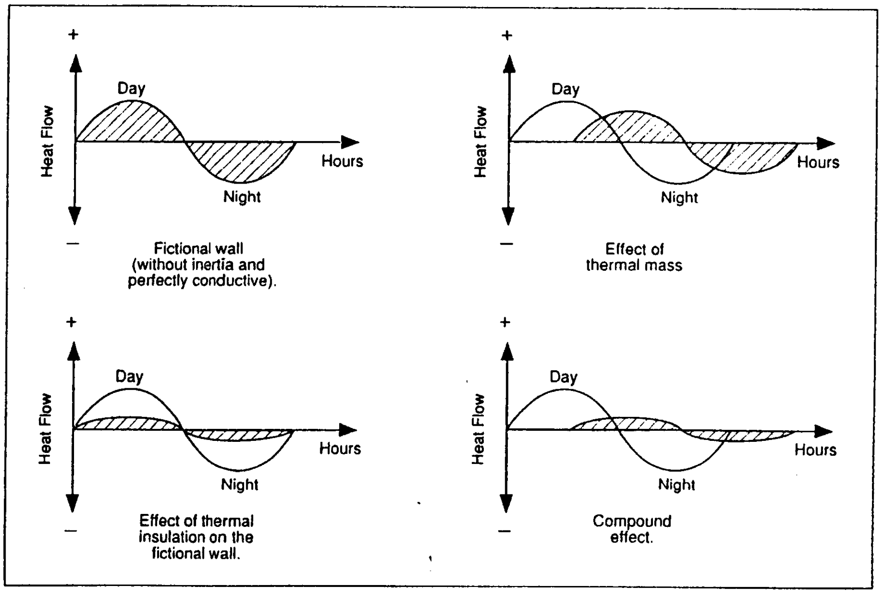


Fig. 78 Bioclimatic Chart



Fictional wall (without inertia and perfectly conductive).

Effect of thermal mass

Effect of thermal insulation on the fictional wall.

Compound effect.

Fig. 79 Effects of Thermal Mass

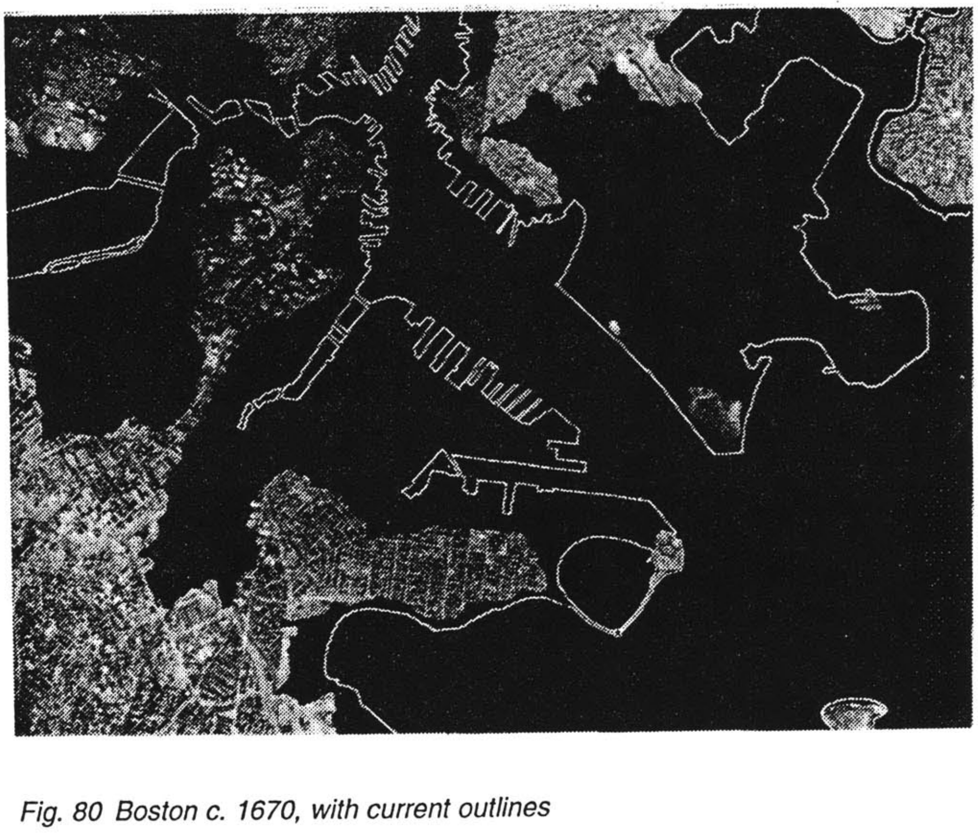


Fig. 80 Boston c. 1670, with current outlines

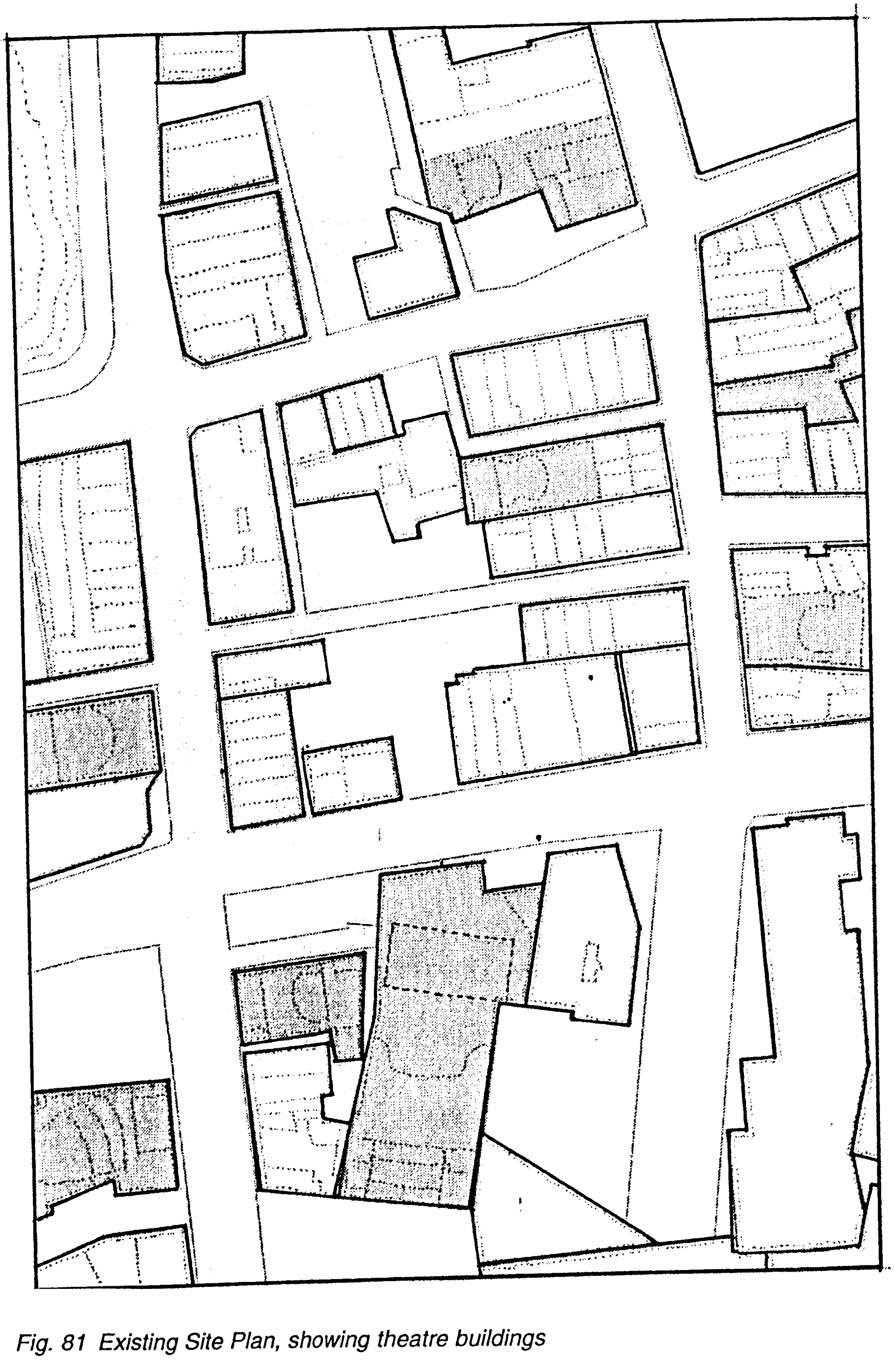


Fig. 81 Existing Site Plan, showing theatre buildings

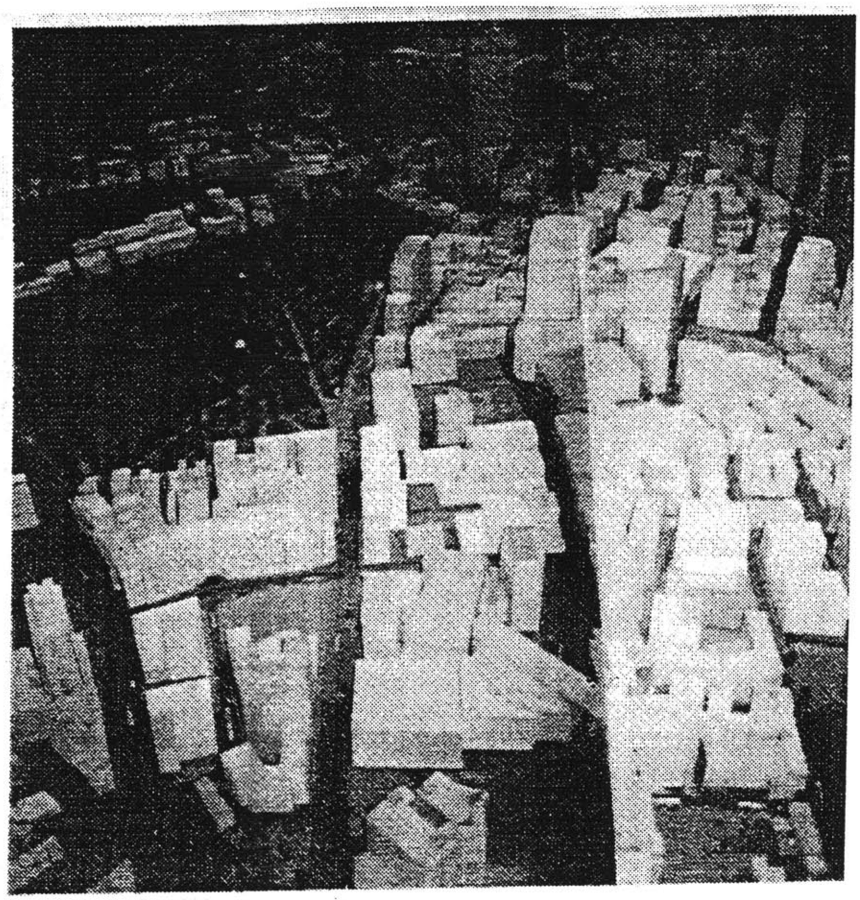


Fig. 82 Model of Site, viewed from South

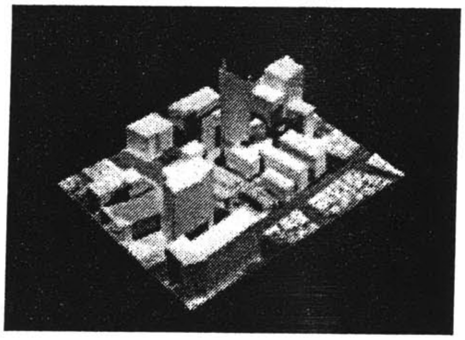


Fig. 83 Study Model

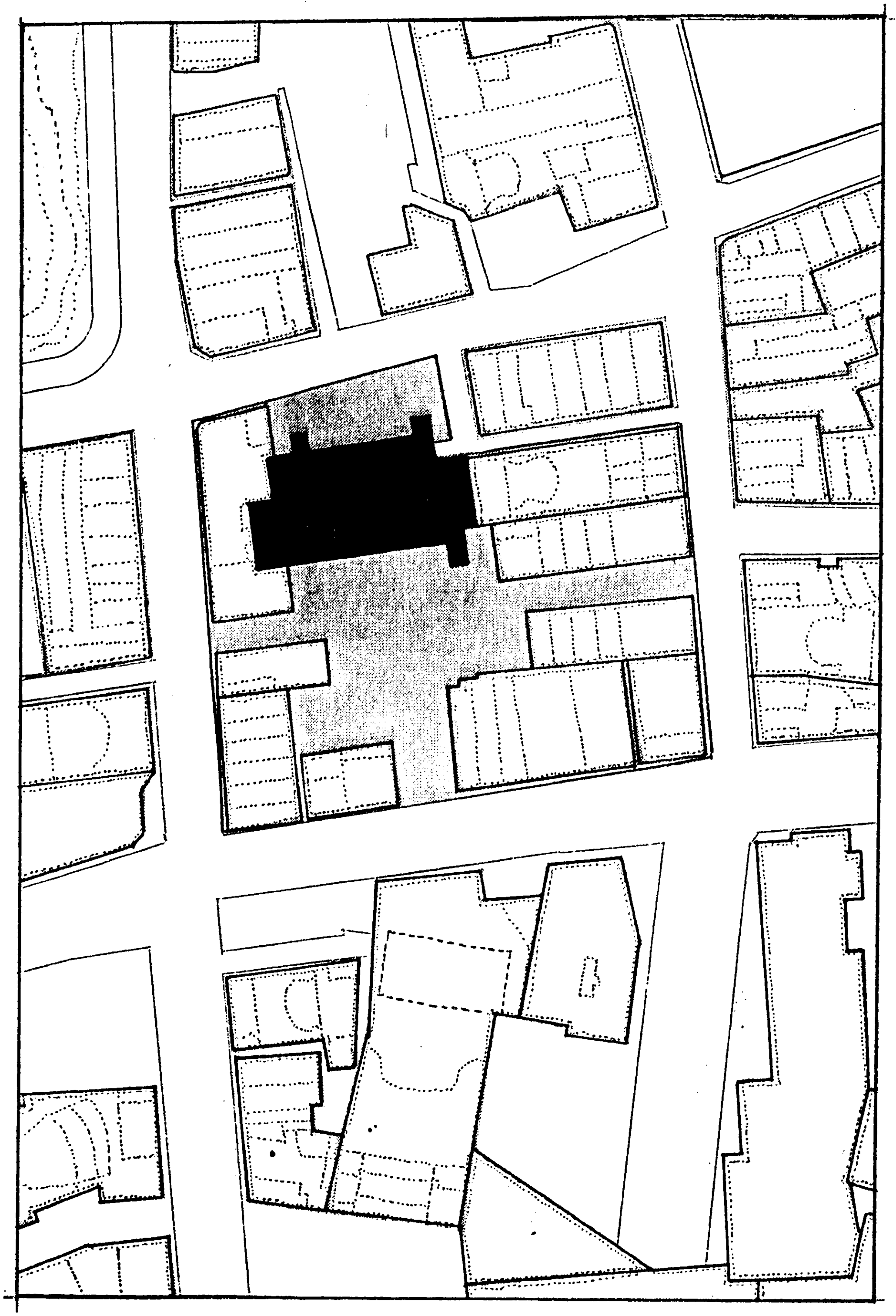


Fig. 84 Proposed Site Plan

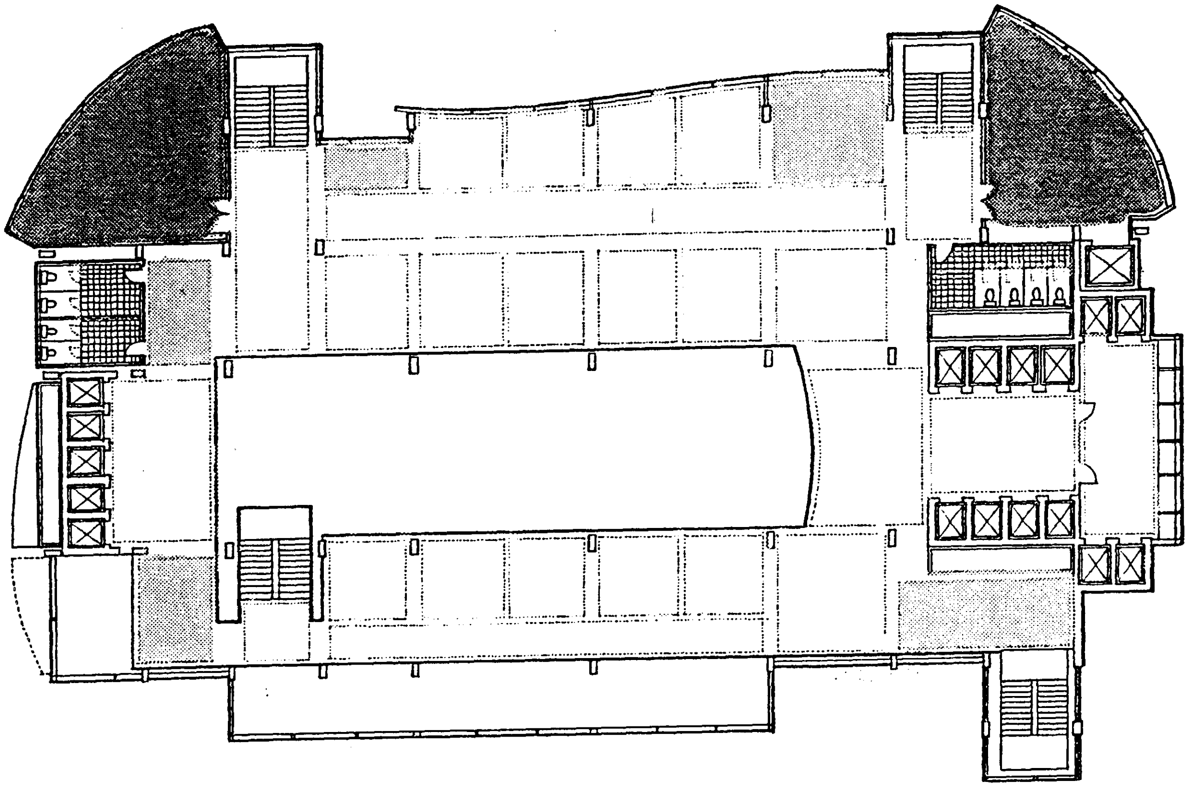


Fig. 86 Intermediate Floor Plan, showing corner elements and South Mezzanine

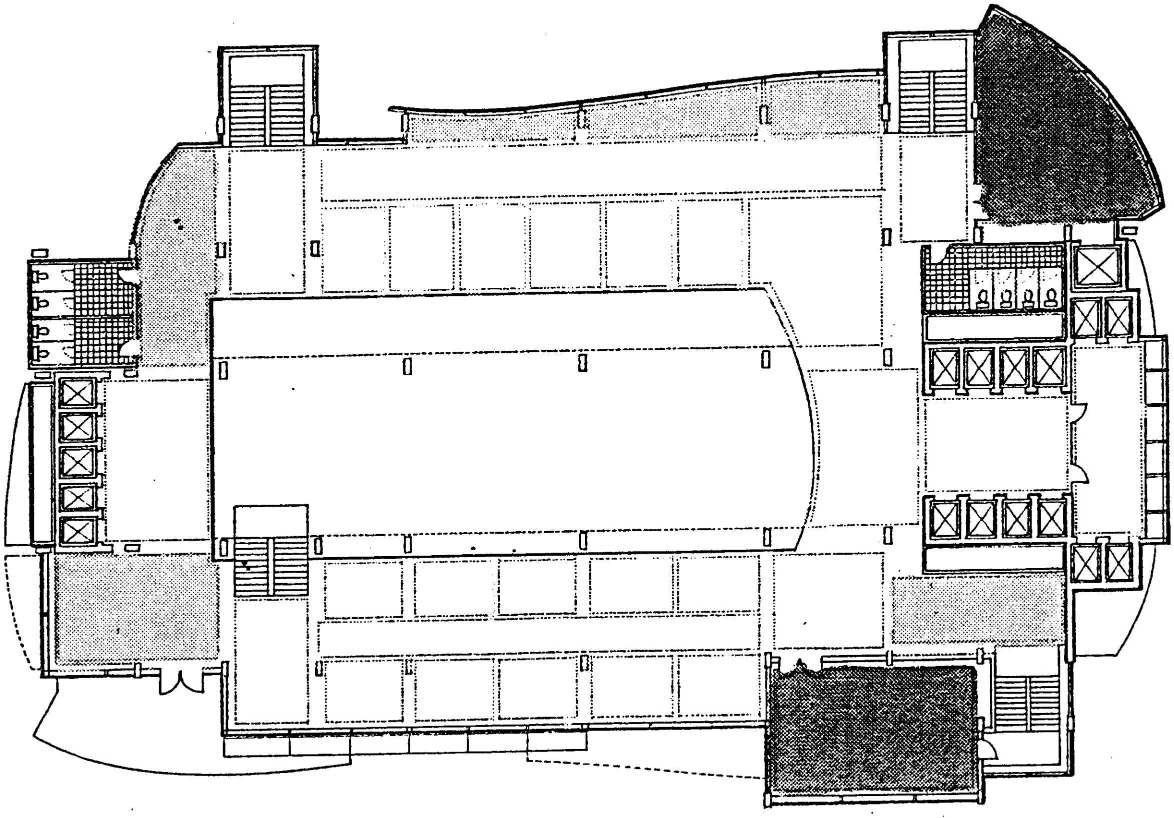


Fig. 87 Intermediate Floor Plan, showing corner elements and North Mezzanine

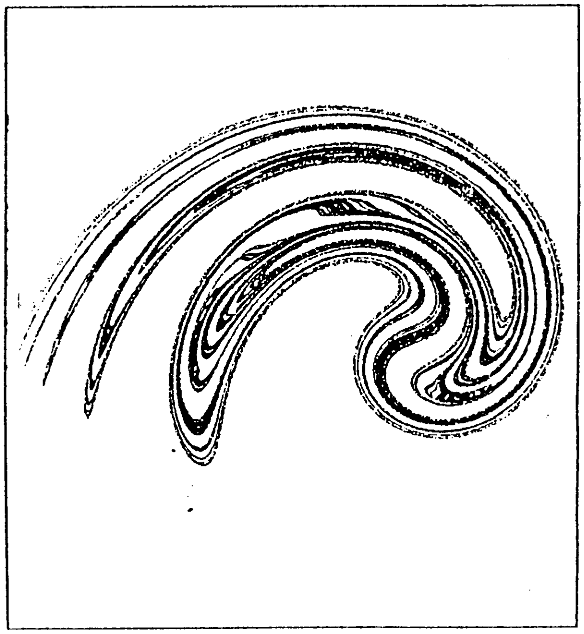


Fig. 88 Phase Plot of an Ikeda Strange Attractor

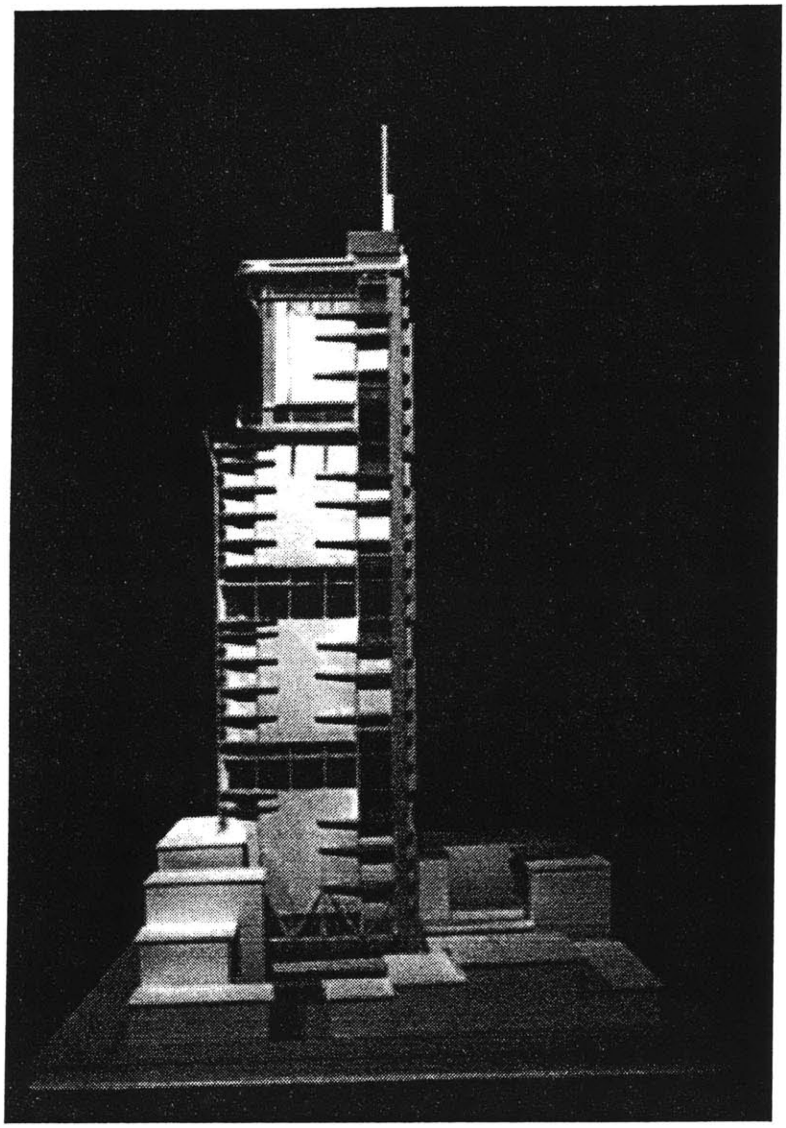


Fig. 89 South Elevation showing hierarchy of elements

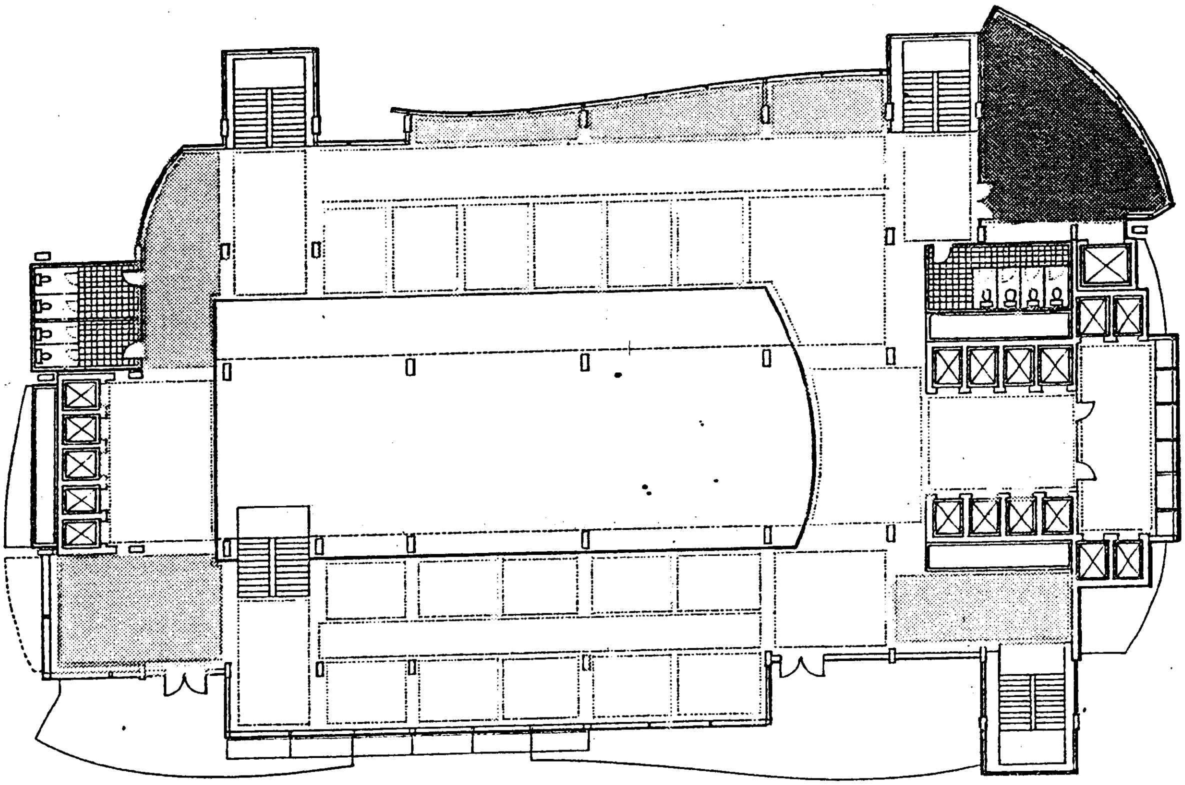


Fig. 90 Intermediate Plan showing Southern Balconies

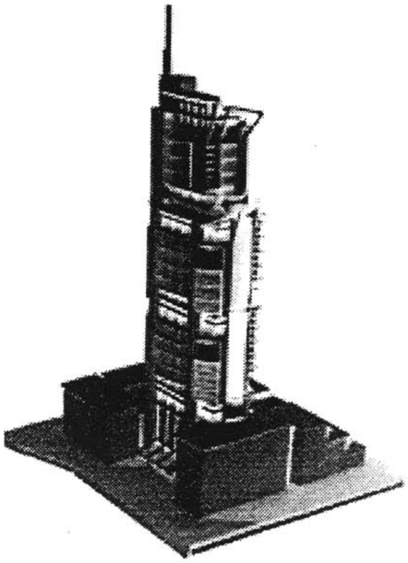


Fig. 91. Model from Northwest

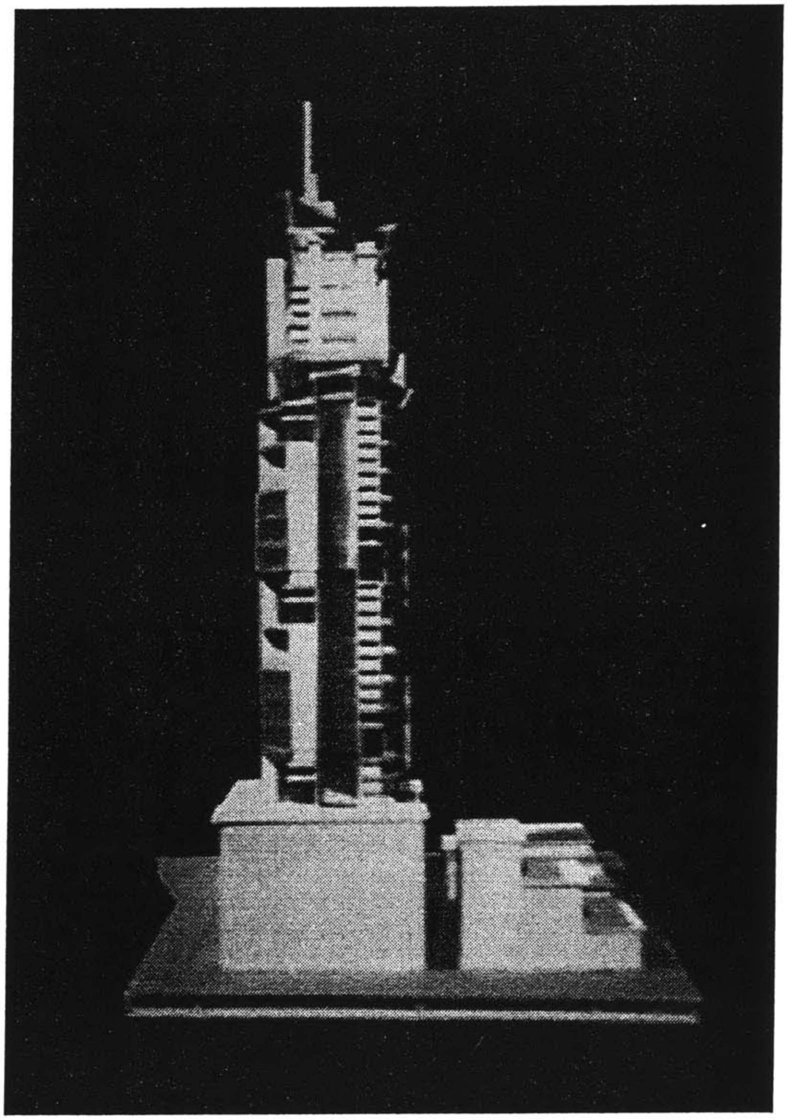


Fig. 92 Western Elevation showing re-use of the existing buildings

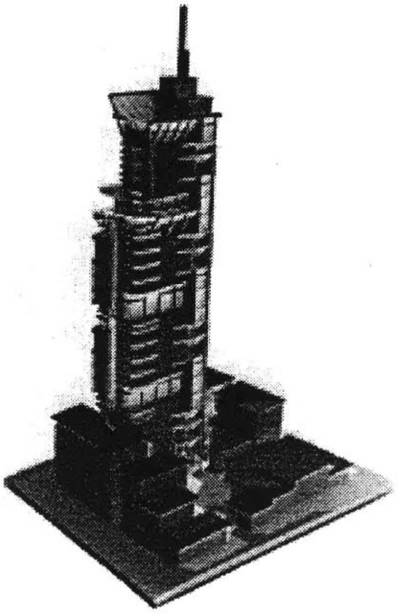


Fig. 93 Model from Southwest

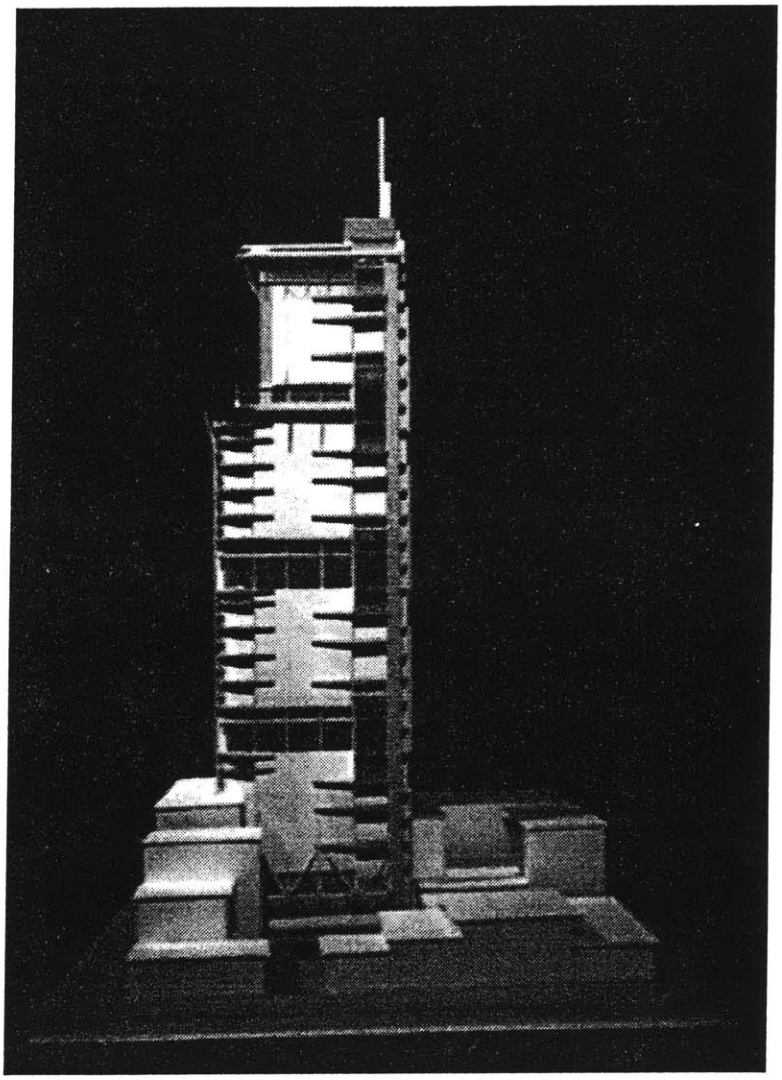


Fig. 94 Southern Elevation showing base of building

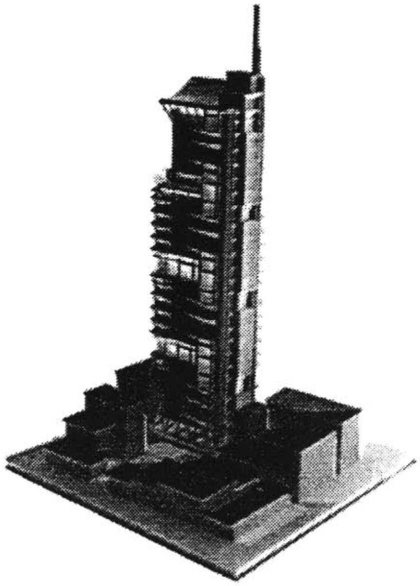


Fig. 95 Model from Southeast

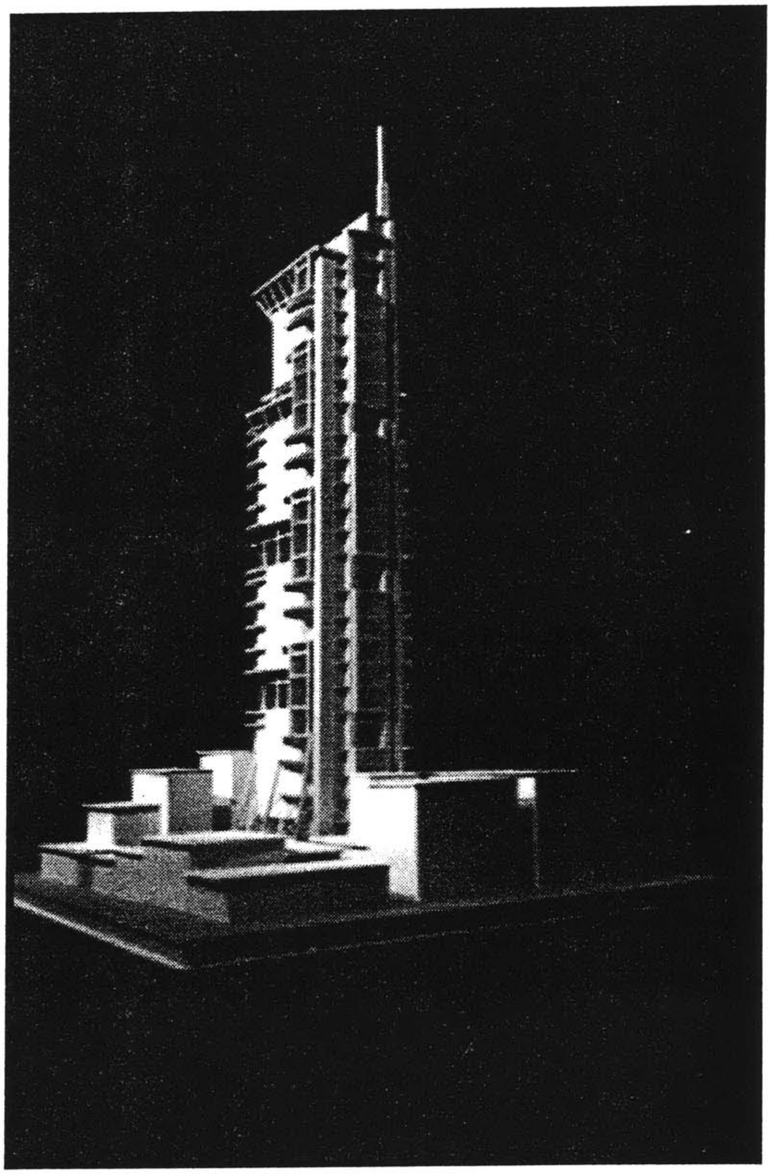


Fig. 96 View from Southeast showing vertical circulation elements

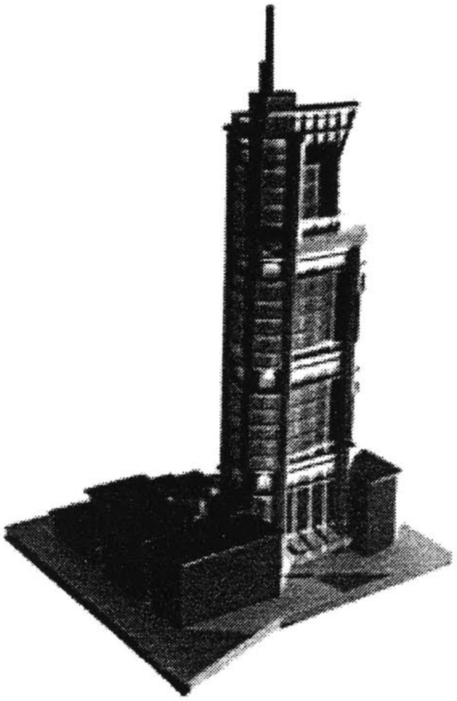


Fig. 97 Model from Northeast

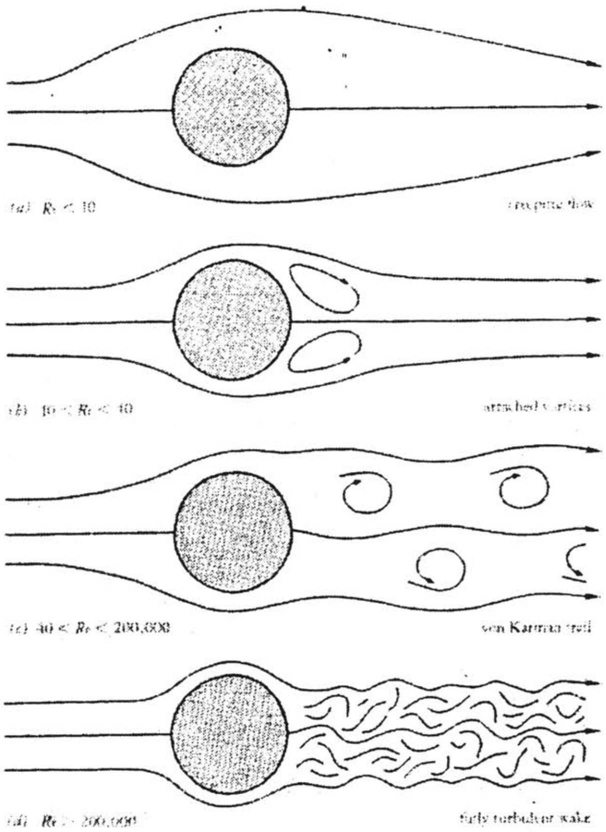


Fig. 98 Airflow Studies

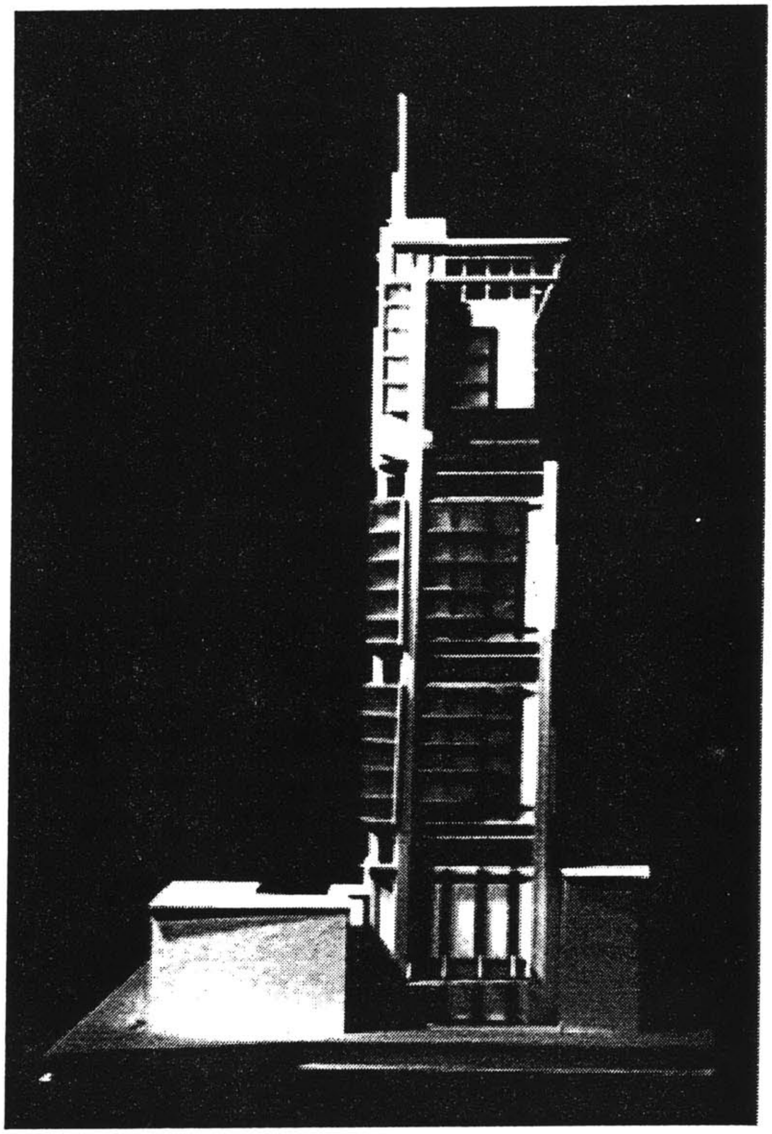


Fig. 99 North Elevation showing curved facade elements

Five Strategies for Airflow

- Shield the Northern Exposure from High Winds -------------------
- Use Prevailing Winds to Generate Power and Draw Out the Atrium Air. -----------------------
- Use Envelope Elements to Pull Air Around the Building ----------------
- Use Plenum Floors for Fresh Air Intakes ---------------------
- Protect the Base of the Building from Turbulence -------------------

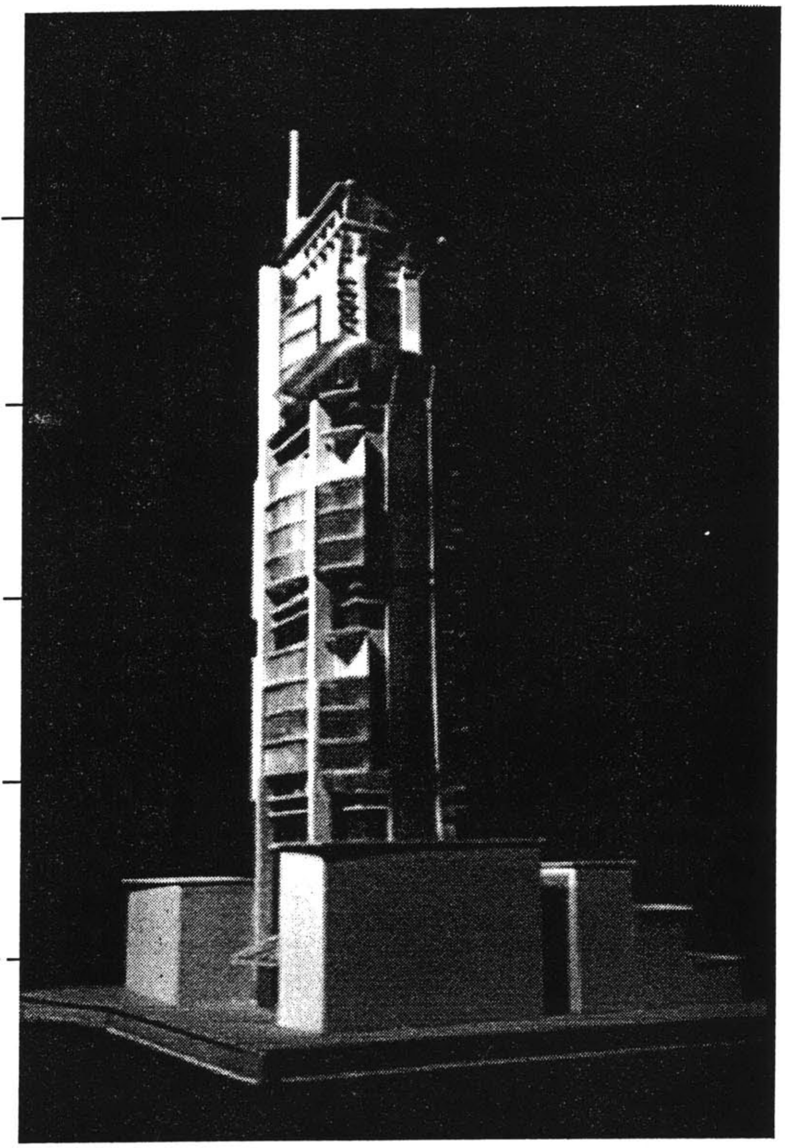


Fig. 100 Model from Northwest, showing curved envelope elements

Fig. 101 Turbulent Mixing Patterns

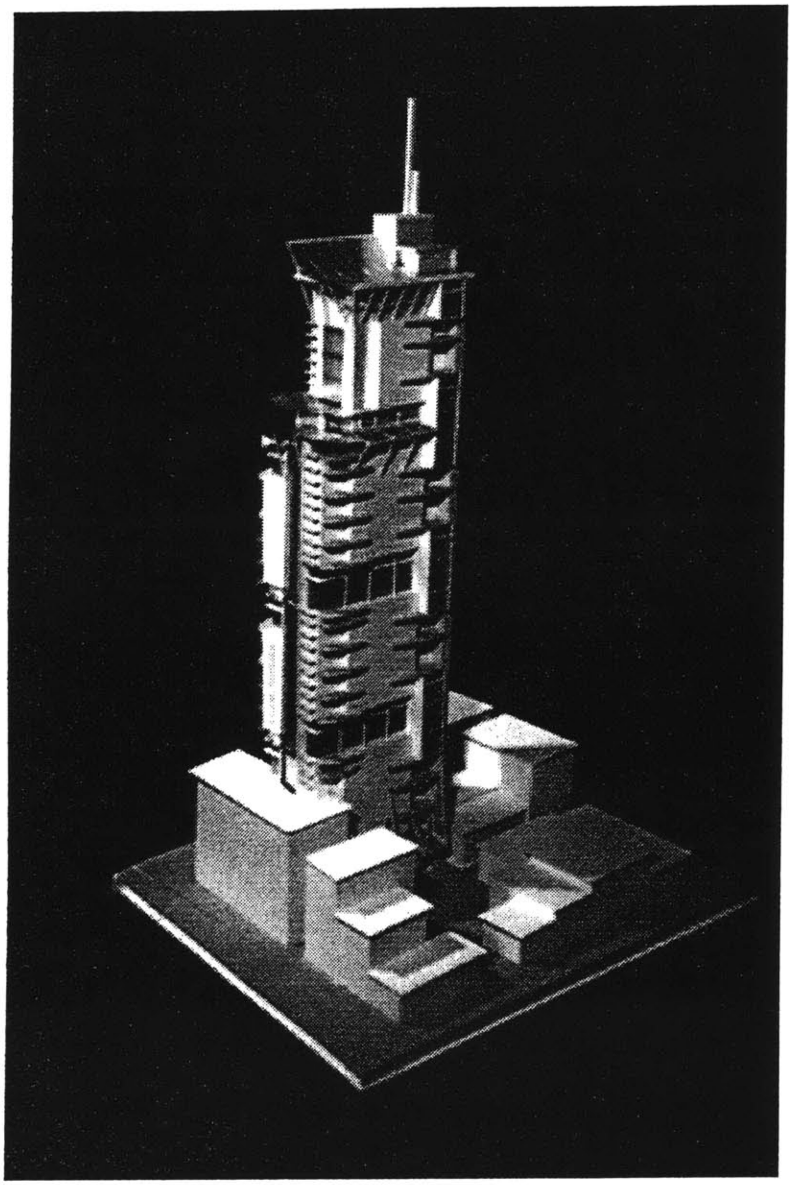


Fig. 102 Model from Southwest

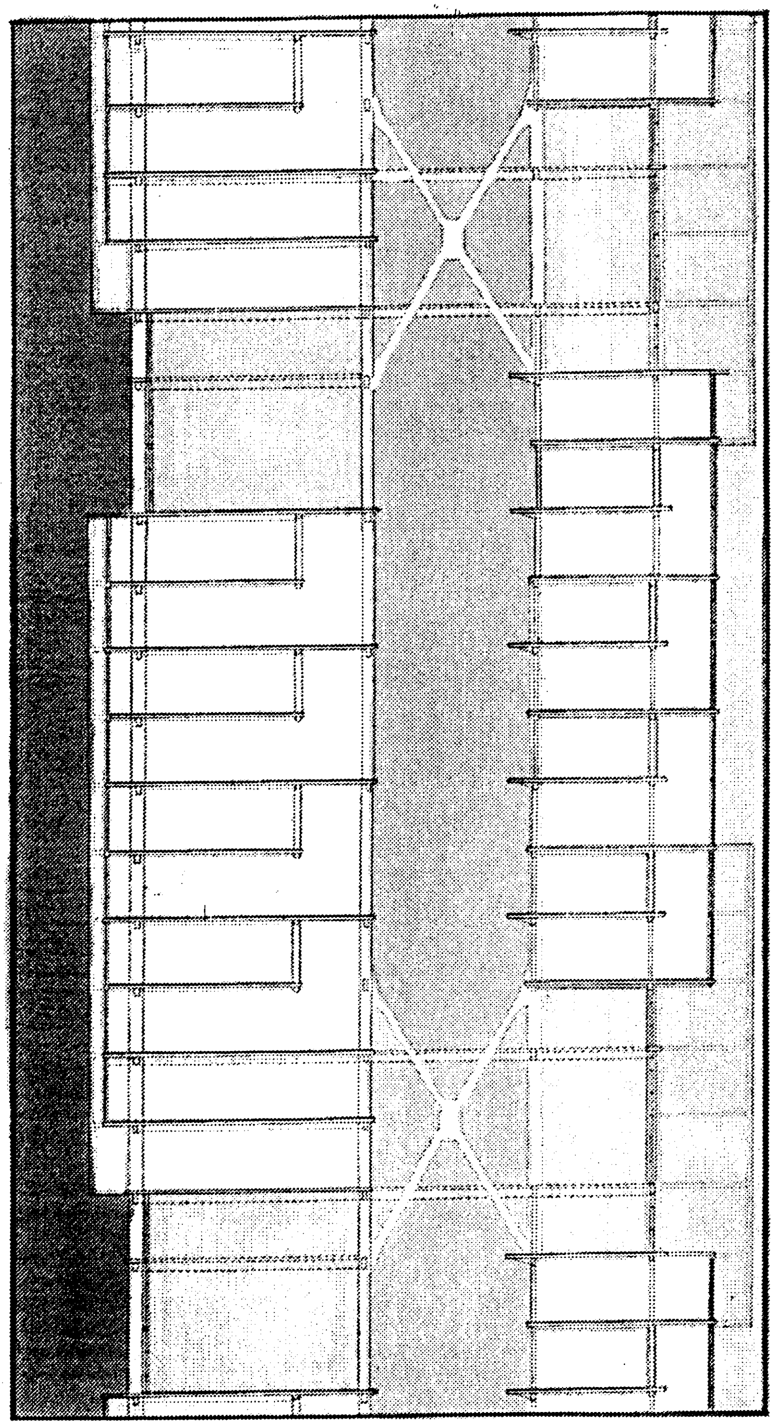


Fig. 103 Section NS Showing Office Bays and Atrium Layering

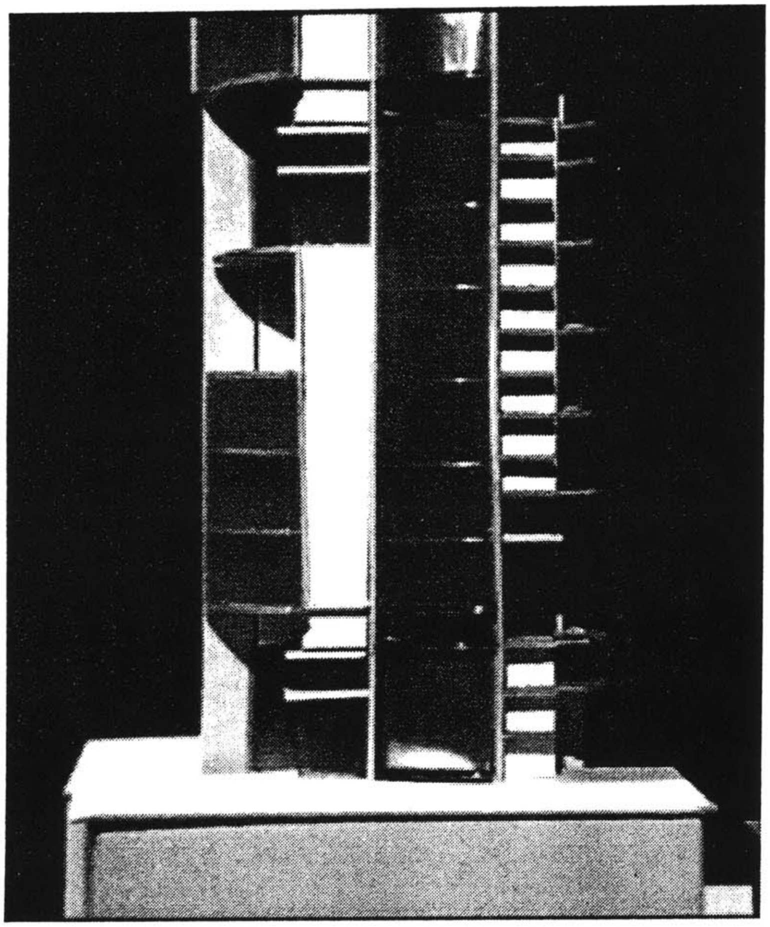


Fig. 104 Detail of West Elevation, showing offset atrium elements

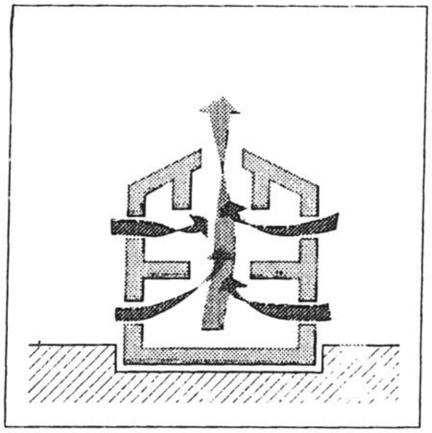


Fig. 105 Atrium Ventilation Diagram

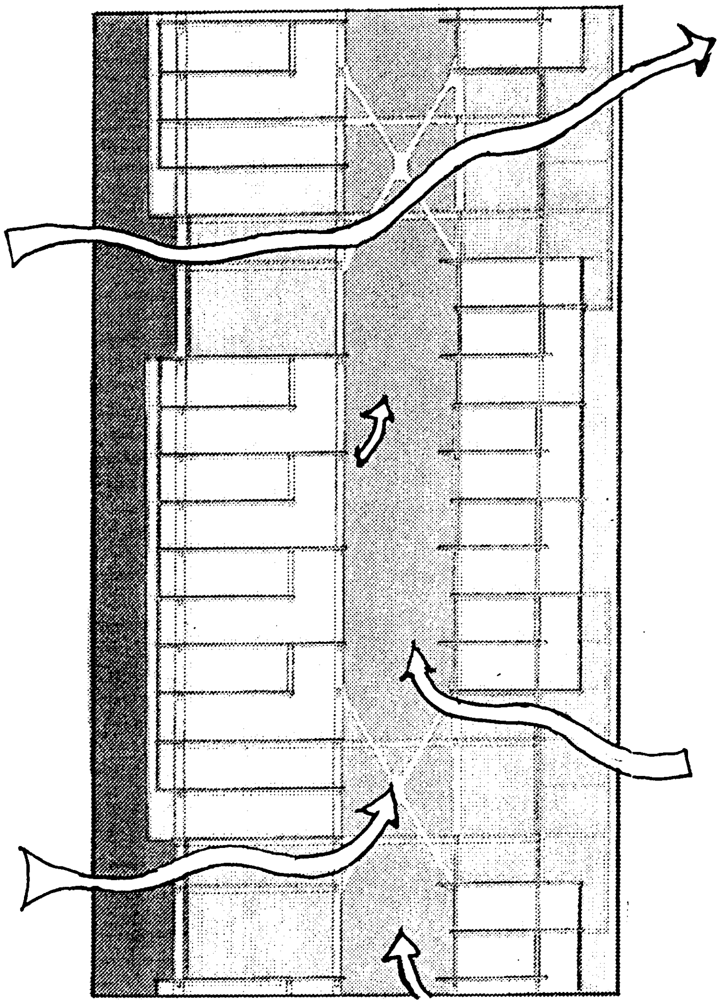


Fig. 106 Sectional Airflow Diagram

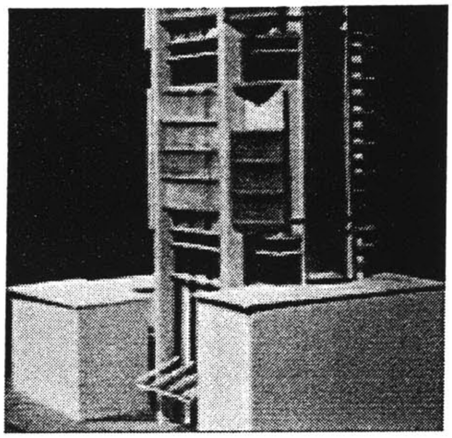


Fig. 107 Model showing North Base

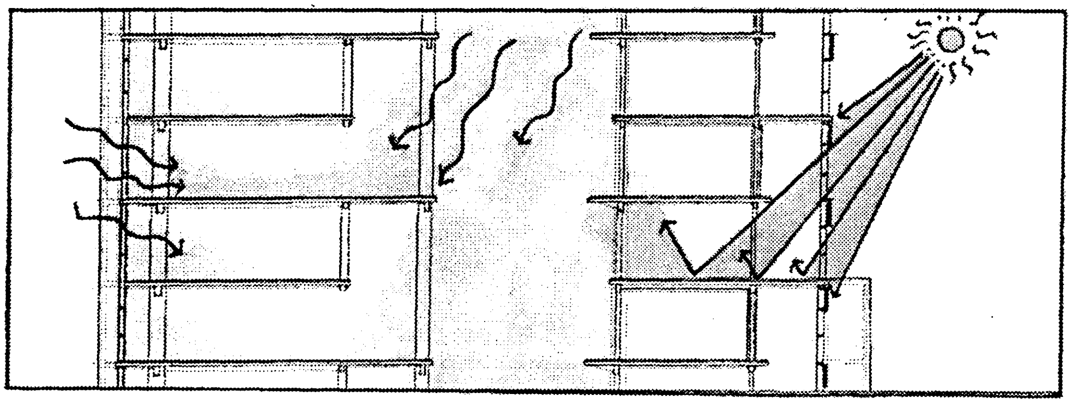


Fig. 108 Summer Daylighting, Direct and Ambient @ 53 degrees inclination

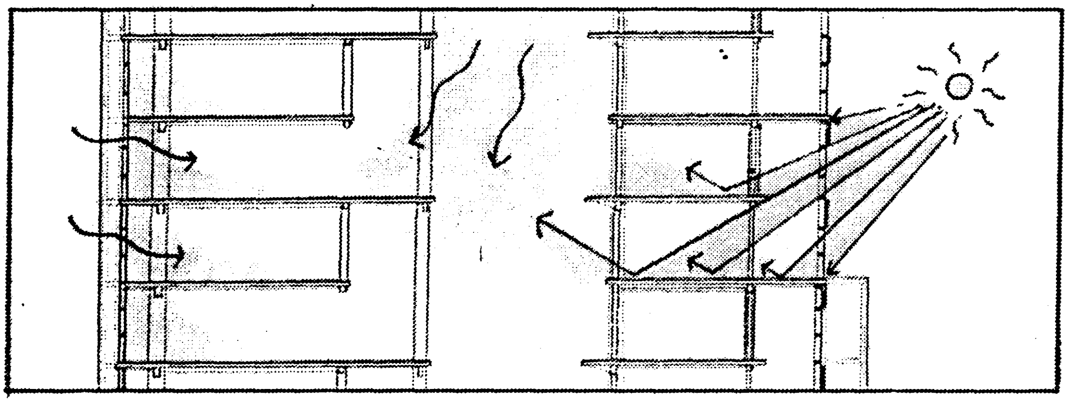


Fig. 109 Winter Daylighting, Direct and Ambient @ 37 degrees inclination

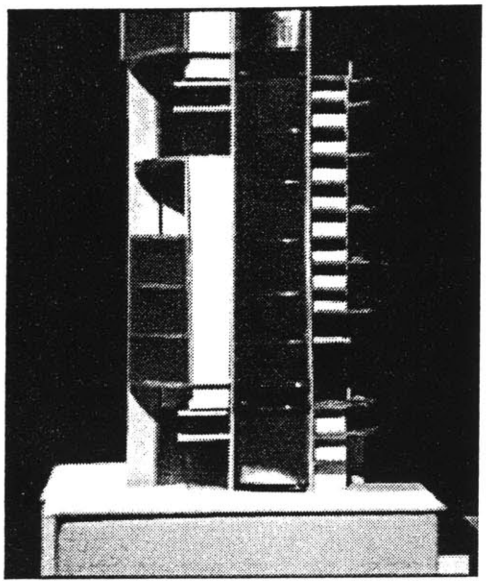


Fig. 110 Model from West

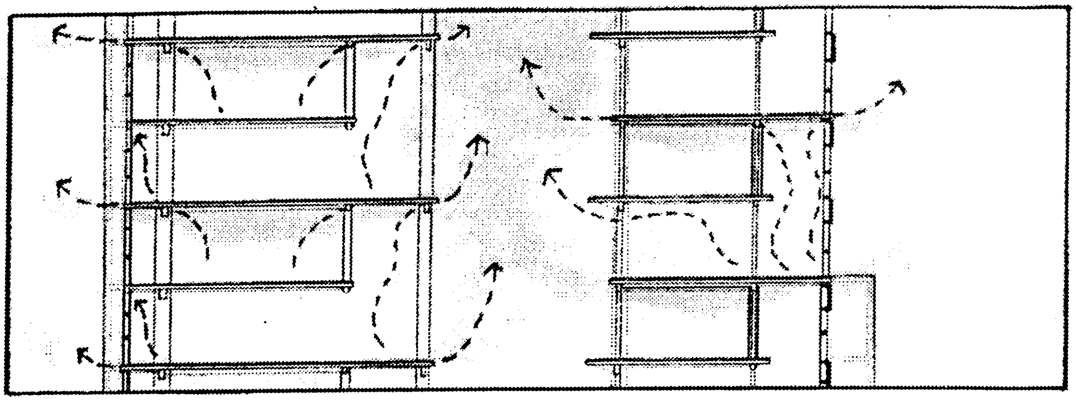


Fig. 111 Summer Airflow -- Daytime

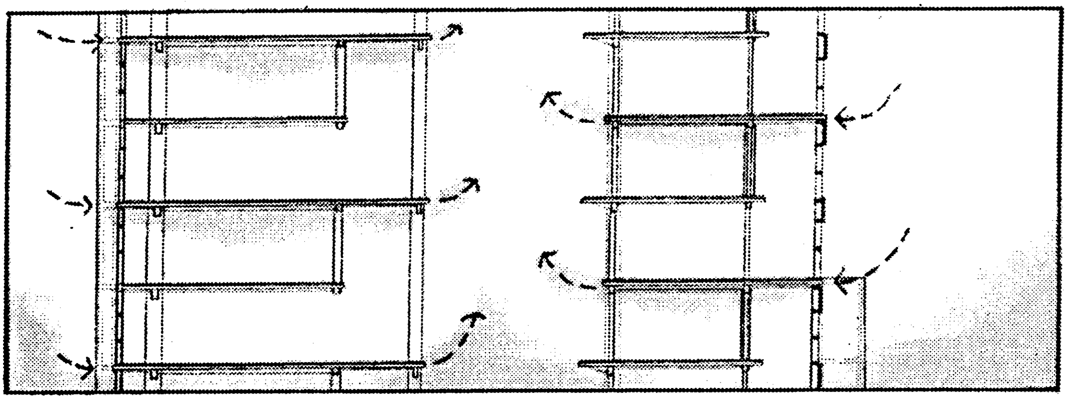


Fig. 112 Summer Airflow -- Nighttime

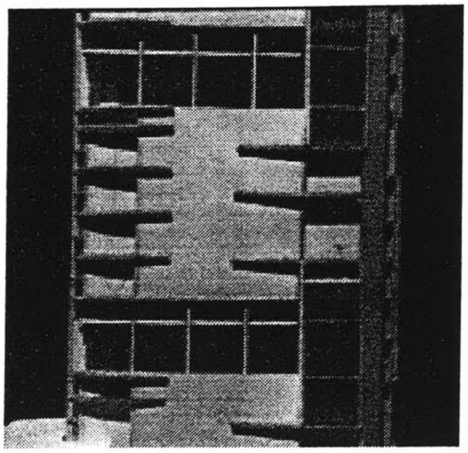


Fig. 113 Model from South

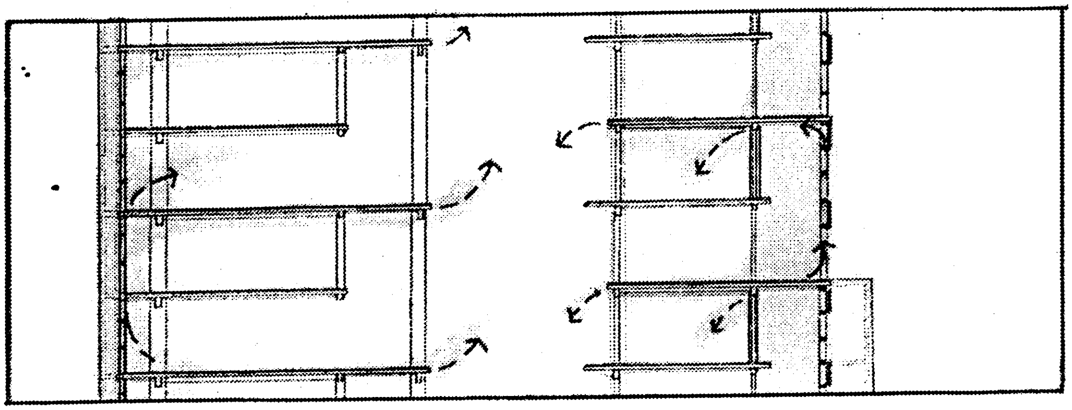


Fig. 114 *Winter Airflow --Daytime*

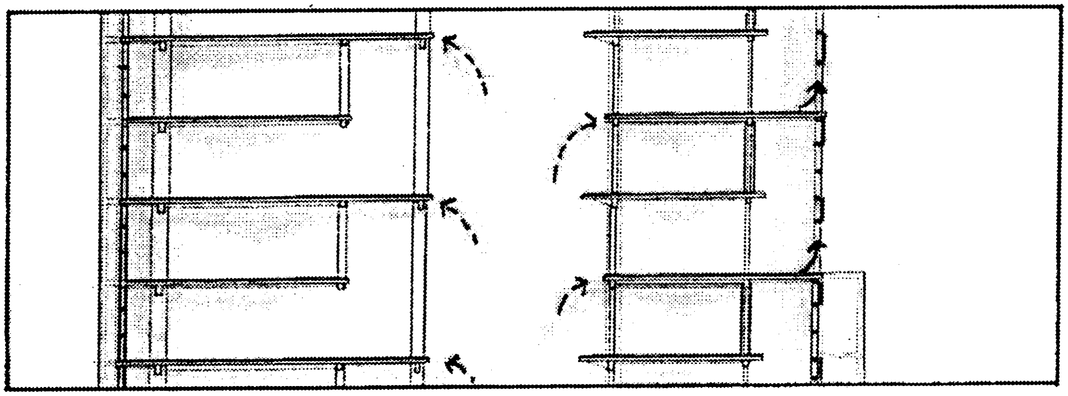


Fig. 115 *Winter Airflow -- Nighttime*

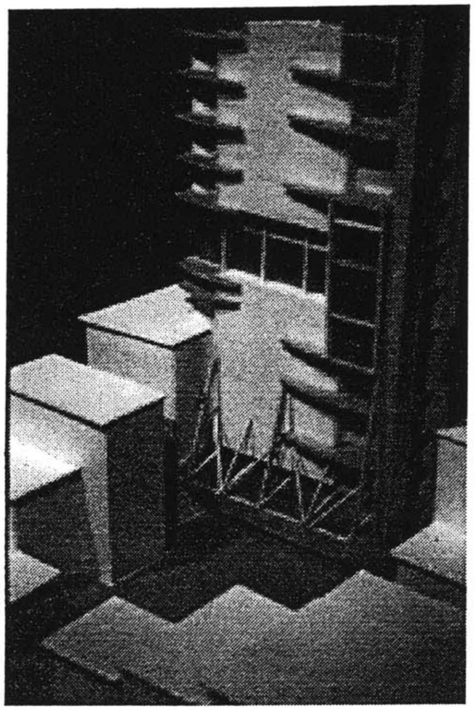


Fig. 116 Model showing courtyard at base

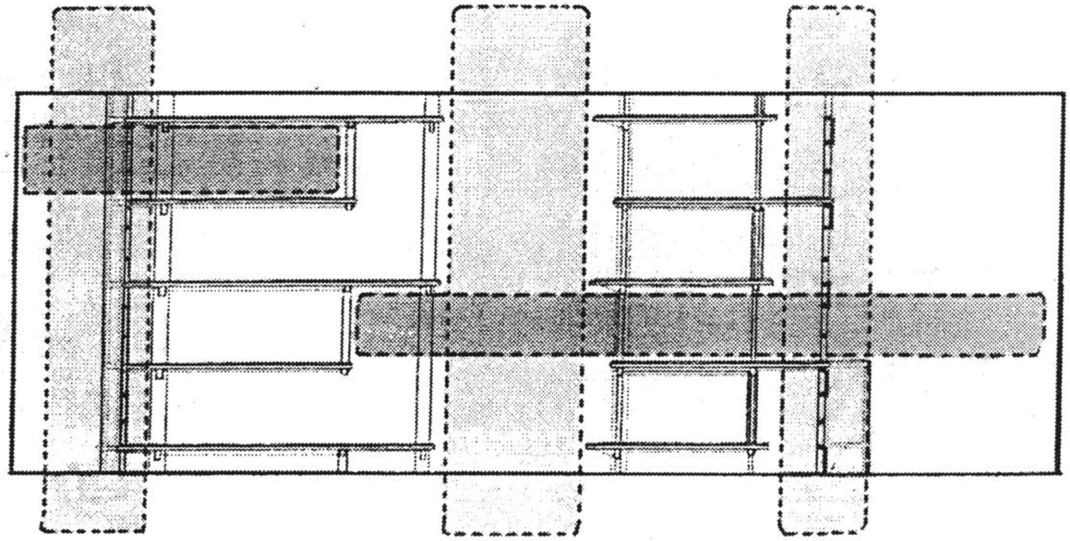


Fig. 117 Sectional Layers

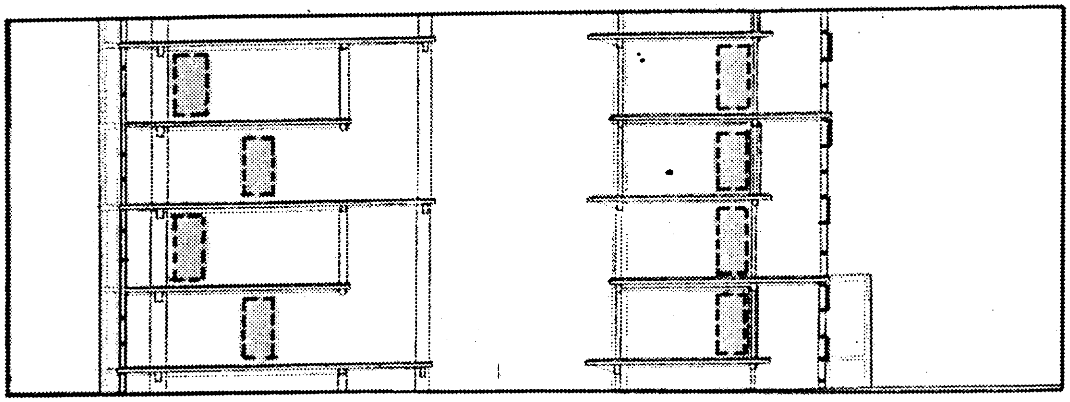


Fig. 118 Circulation Zones in Section

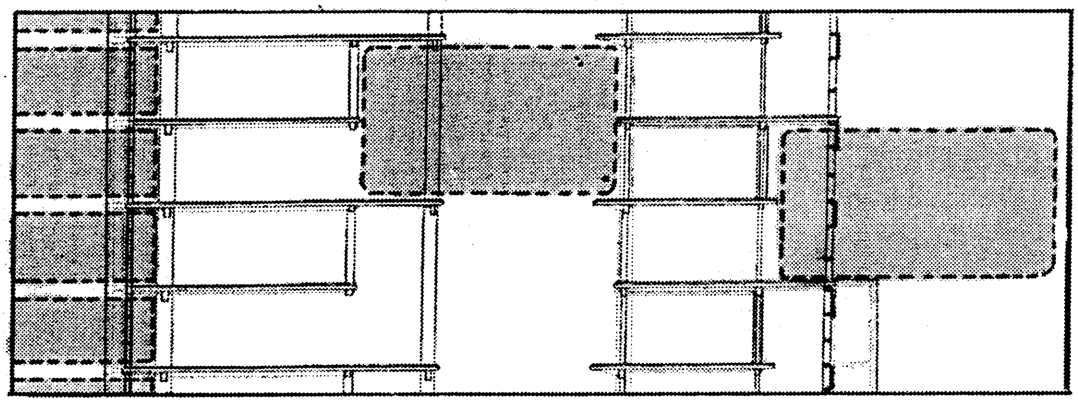
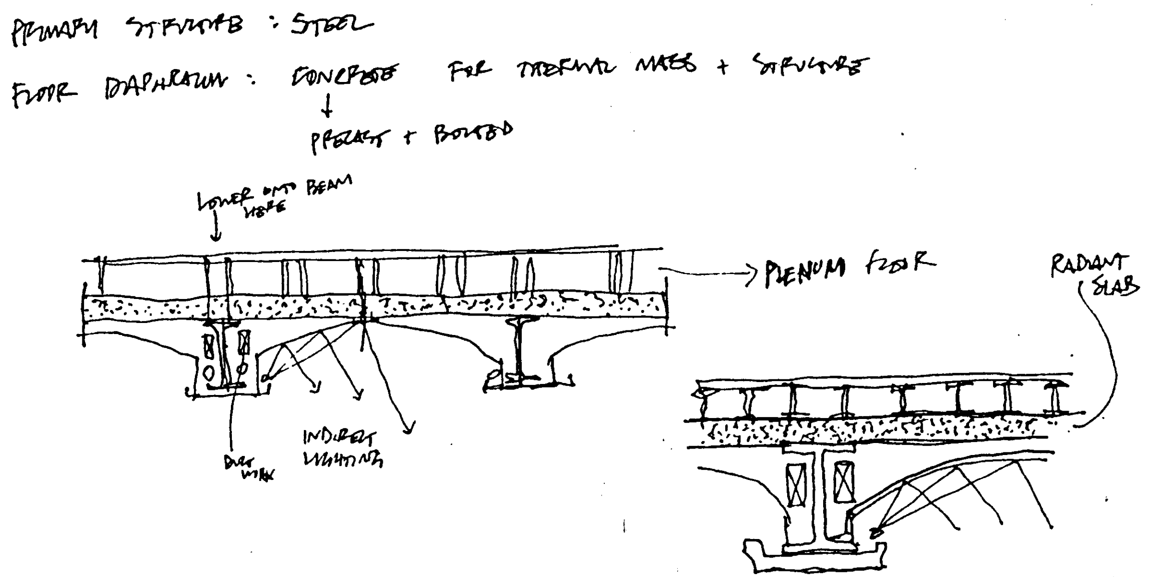


Fig. 119 Spatial Zones and Microclimates



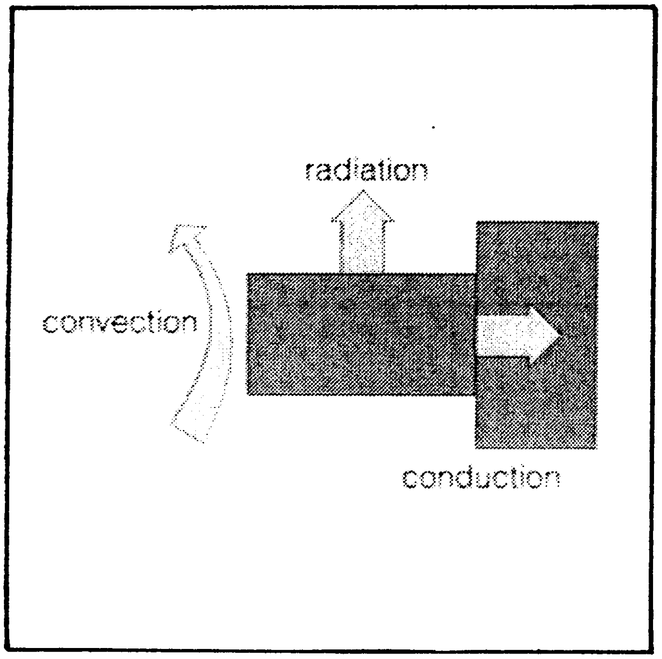


Fig. 120 Heat Transfer Mechanisms

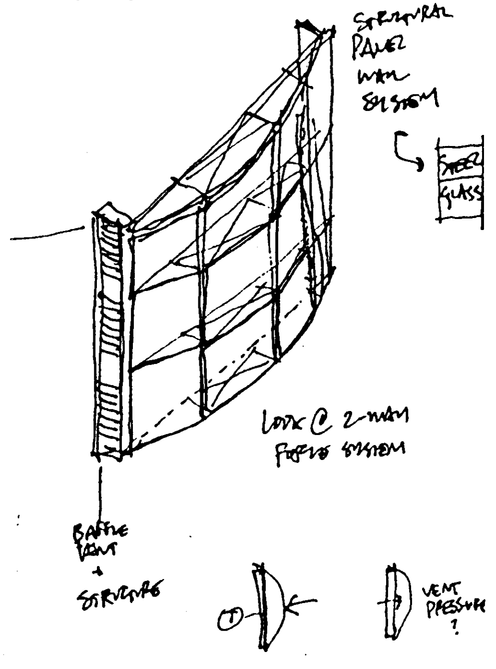


Fig. 121 Detail Development

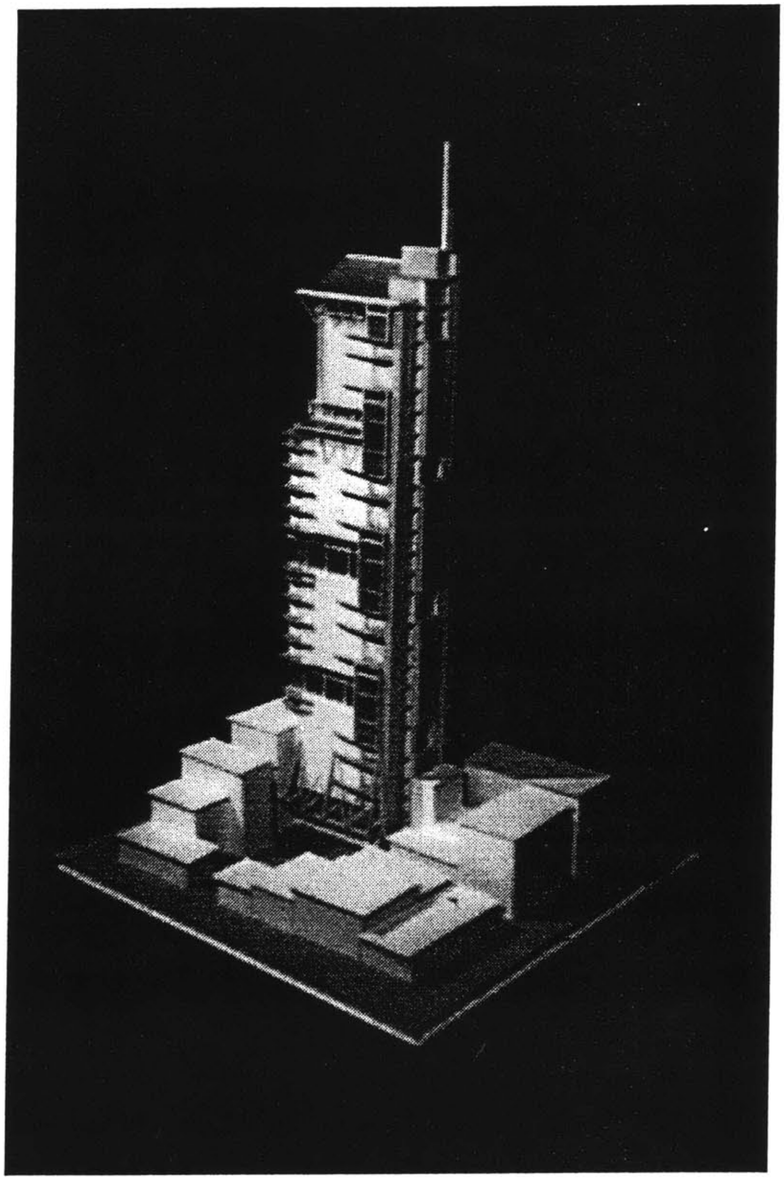
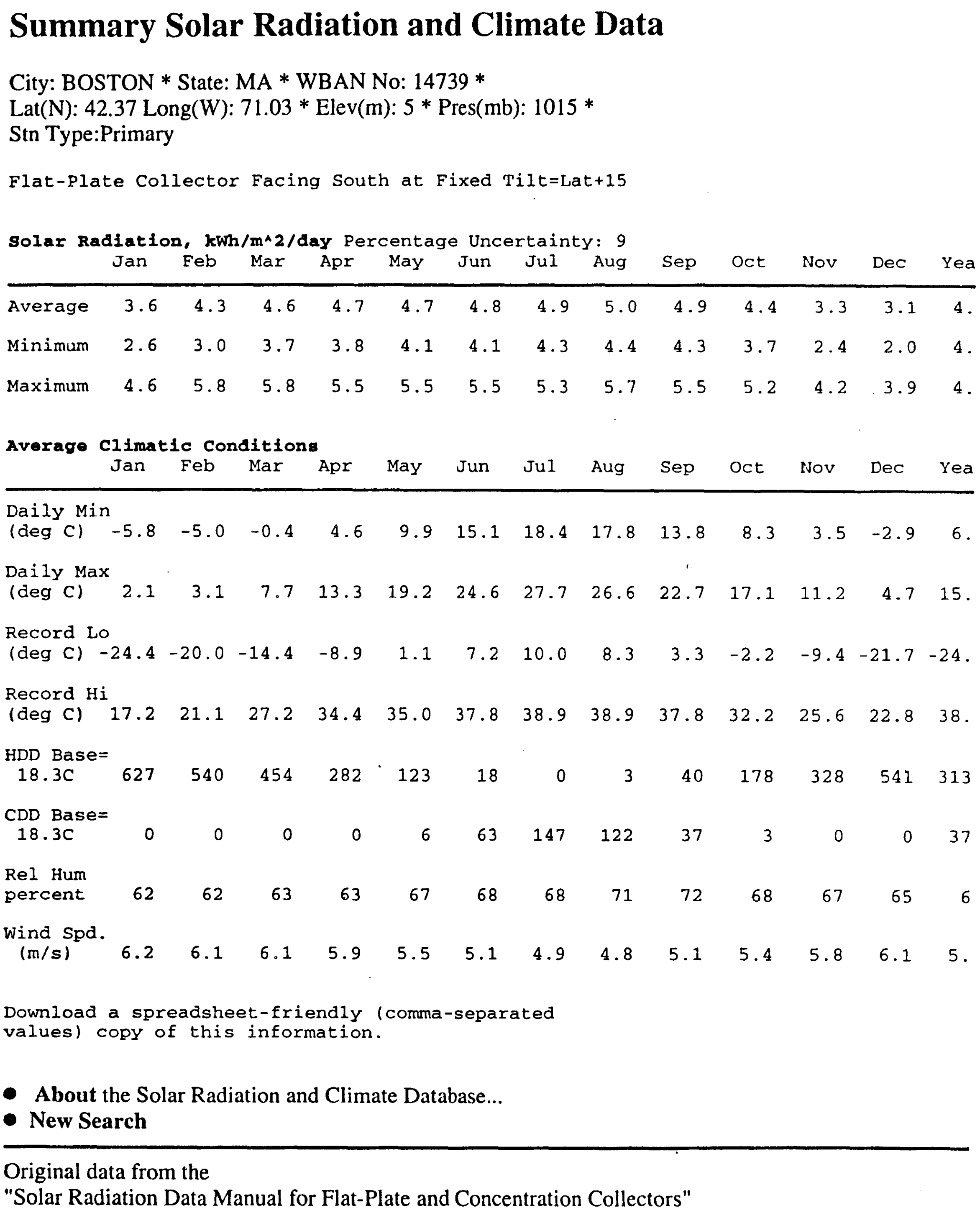


Fig. 122 Model from Southeast



Summary Solar Radiation and Climate Data

City: BOSTON * State: MA * WBAN No: 14739 *
Lat(N): 42.37 Long(W): 71.03 * Elev(m): 5 * Pres(mb): 1015 *
Stn Type:Primary

Flat-Plate Collector Facing South at Fixed Tilt=Lat+15

Solar Radiation, kWh/m^2/day Percentage Uncertainty: 9

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yea
Average	3.6	4.3	4.6	4.7	4.7	4.8	4.9	5.0	4.9	4.4	3.3	3.1	4.
Minimum	2.6	3.0	3.7	3.8	4.1	4.1	4.3	4.4	4.3	3.7	2.4	2.0	4.
Maximum	4.6	5.8	5.8	5.5	5.5	5.5	5.3	5.7	5.5	5.2	4.2	3.9	4.

Average Climatic Conditions

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yea
Daily Min (deg C)	-5.8	-5.0	-0.4	4.6	9.9	15.1	18.4	17.8	13.8	8.3	3.5	-2.9	6.
Daily Max (deg C)	2.1	3.1	7.7	13.3	19.2	24.6	27.7	26.6	22.7	17.1	11.2	4.7	15.
Record Lo (deg C)	-24.4	-20.0	-14.4	-8.9	1.1	7.2	10.0	8.3	3.3	-2.2	-9.4	-21.7	-24.
Record Hi (deg C)	17.2	21.1	27.2	34.4	35.0	37.8	38.9	38.9	37.8	32.2	25.6	22.8	38.
HDD Base= 18.3C	627	540	454	282	123	18	0	3	40	178	328	541	313
CDD Base= 18.3C	0	0	0	0	6	63	147	122	37	3	0	0	37
Rel Hum percent	62	62	63	63	67	68	68	71	72	68	67	65	6
Wind Spd. (m/s)	6.2	6.1	6.1	5.9	5.5	5.1	4.9	4.8	5.1	5.4	5.8	6.1	5.

Download a spreadsheet-friendly (comma-separated values) copy of this information.

- **About** the Solar Radiation and Climate Database...
- **New Search**

Original data from the
"Solar Radiation Data Manual for Flat-Plate and Concentration Collectors"

Fig. 123 *Solar Radiation Data*

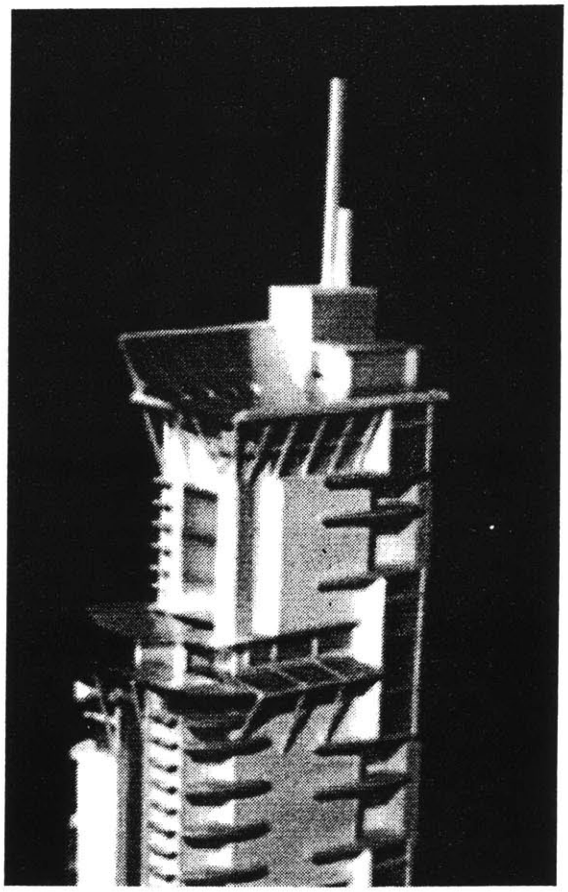
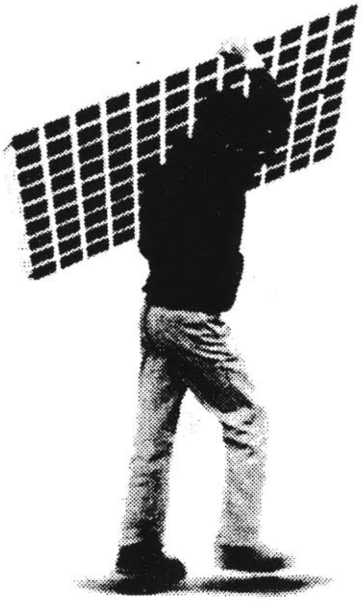


Fig. 125 View of Solar Collector System at Roof Level



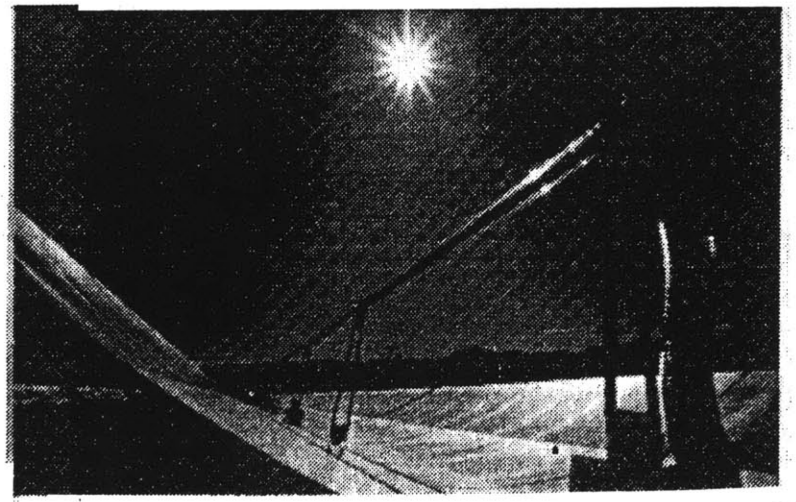


Fig. 124 Human Scaled Elements

Fig. 126 Solar Collector with Oil Conduit, heated to 700 ' F

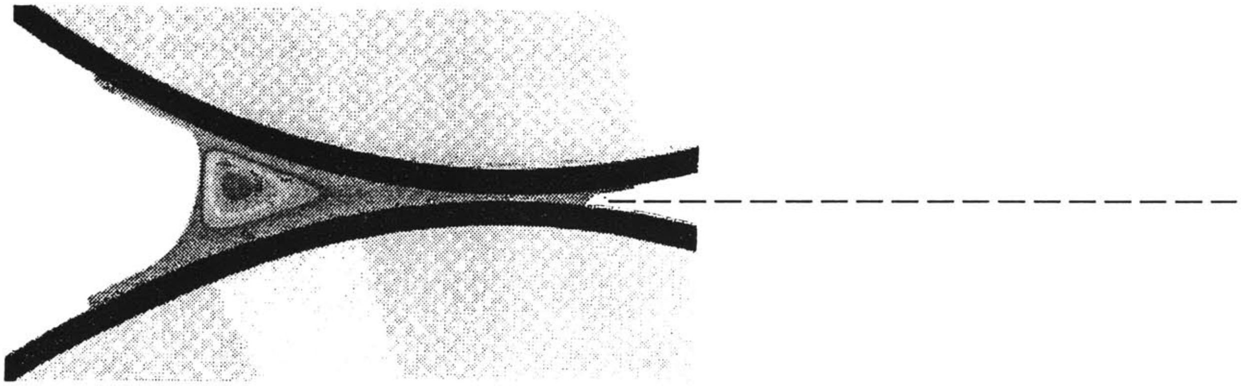


Fig. 127 Wind Accelerator Diagram

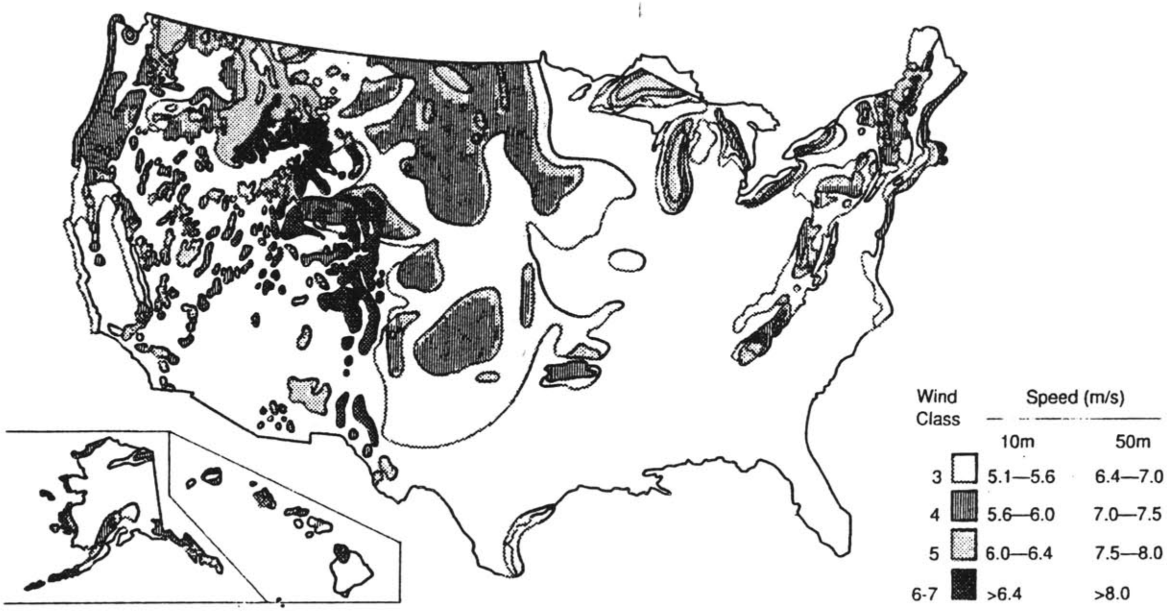
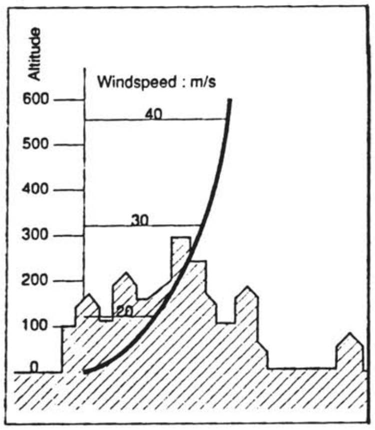


Fig. 128 US Wind Energy Capacity based on Geographic Factors



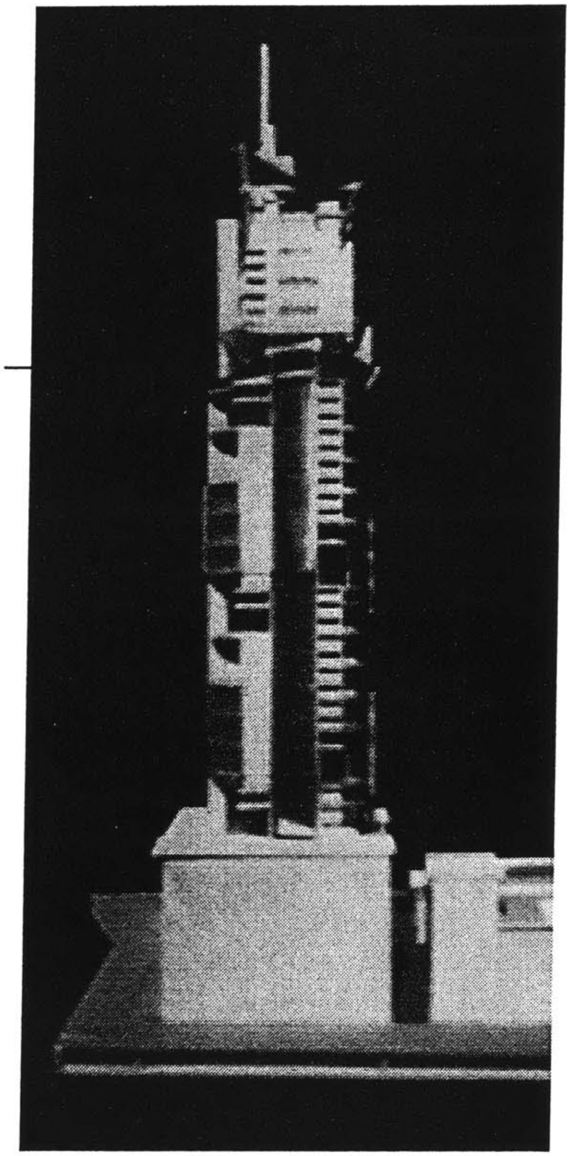


Fig. 129 *Wind Velocity Profile*

Fig. 130 *Model from West showing vertical layering*

"You can only be
As wise as you are;

Later you can only be
Wiser than you were."

--Stymean Karlen

Conclusion

The purpose of this Thesis was to explore the interaction of building form and environmental dynamics using as a theoretical basis the writings of Gottfried Semper on function in design. By extending this conceptual framework and addressing contemporary scientific knowledge, this exercise has proved fruitful in characterizing several technical issues as architectural questions.

The more influential of these questions were the notion of engaging airflow and windform through building tectonics, and the issue of productivity and its relation to design. By addressing the first in terms of a use / form / technology / environment hierarchy, decisions which enabled architectural solutions — as opposed to technical ones — could be prioritized and action taken upon them, evolving as the building form.

By investigating the foundations of the latter issue, productivity and its place in the design process, the role of architectural knowledge in the modern cultural context shone clearly as one through which true value can be sought from the design process. Although this capacity for economic context is valuable, this project has shown me that any good architectural question must be phrased, tested, and answered as a three dimensional proposal. Without this emphasis, one can only take sides, and not lead.

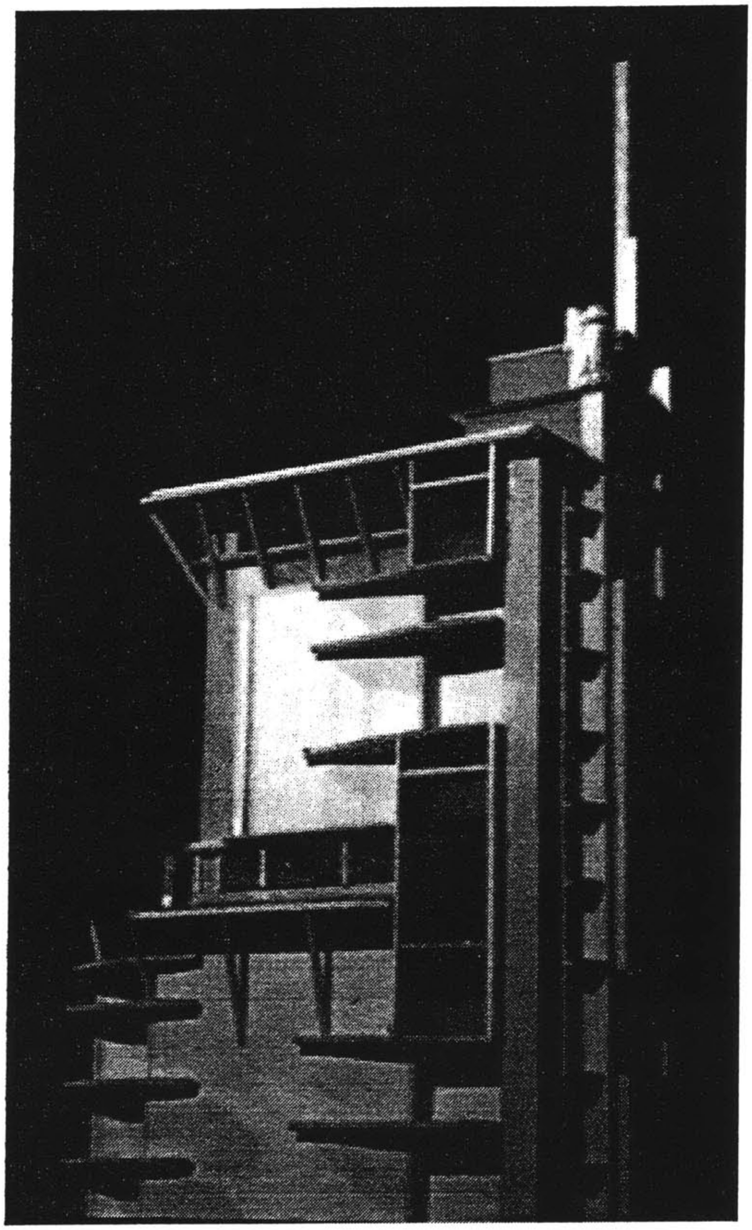


Fig. 131 View of the Protective Gargoyle, top right

The tensions between art and engineering, as well as tradition and innovation, are an essential aspect of modernity. One cannot resolve the question of dominance and probably need not in any case, excepting that the tension should be recongnized and an attempt made to understand several points of view. Regarding the "scientification" of architecture, I find myself with allegiances to the fullest understanding of Semper's "functionality" — knowing that architecture holds a poetic power which can — and will — overcome any formulation of particular conditions, answering to a holistic matrix of determinants and yet maintaining the singular voice of specificity — in place, in time, and in continuous use.

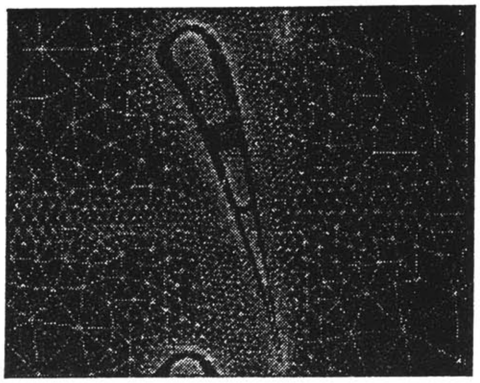


Fig. 132 Fractal Wing

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Figure Credits

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3	Elliot, Technics and Architecture, p. 85.
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Acknowlegements

This Thesis is dedicated to my wife, Catherine Elizabeth Anderson, who was bold enough to accept the terms of this project as a condition of marriage. I look forward to reminding ourselves that these were *not* the "good old days".

In addition, I would like to acknowledge the unfailing support of my family, in all its system boundaries. May the culmination of this Thesis allow us all the more reason to share precious time together.

Thank you to all who helped.
You are well remembered.

Cambridge, MA
January 1996.