Variable Volume Architecture: *Expanding the Boundary*

by

Asheshh Saheba

Bachelor of Architecture
The University of Texas at Austin, 1995

Submitted to the Department of Architecture
in partial fulfillment of the requirements for the degree of
Master of Science in Architecture Studies
at the
Massachusetts Institute of Technology
June 2001

© 2001 Asheshh Saheba. All rights reserved.
The author hereby grants to MIT permission to reproduce
and to distribute publicly paper and electronic
copies of this thesis document in whole or in part.

Signature of Author: Asheshh Saheba
Department of Architecture
24 May 2001

Certified by: John Fernandez
Assistant Professor of Building Technology
Thesis Supervisor

Accepted by: Roy Strickland
Principal Research Scientist in Architecture
Chairman, Departmental Committee on
Graduate Students

MASSACHUSETTS INSTITUTE
OF TECHNOLOGY
JUL 2 4 2001
LIBRARIES

ROTCH

Reader: Stanford Anderson
Professor of History and Architecture
Head, Department of Architecture
Massachusetts Institute of Technology

Reader: Daniel Schodek
Professor of Architecture
Harvard Graduate School of Design

Variable Volume Architecture: *Expanding the Boundary*

by

Asheshh Saheba

Submitted to the Department of Architecture
on the 24th of May 2001 in partial fulfillment of the
requirements for the degree of
Master of Science in Architecture Studies

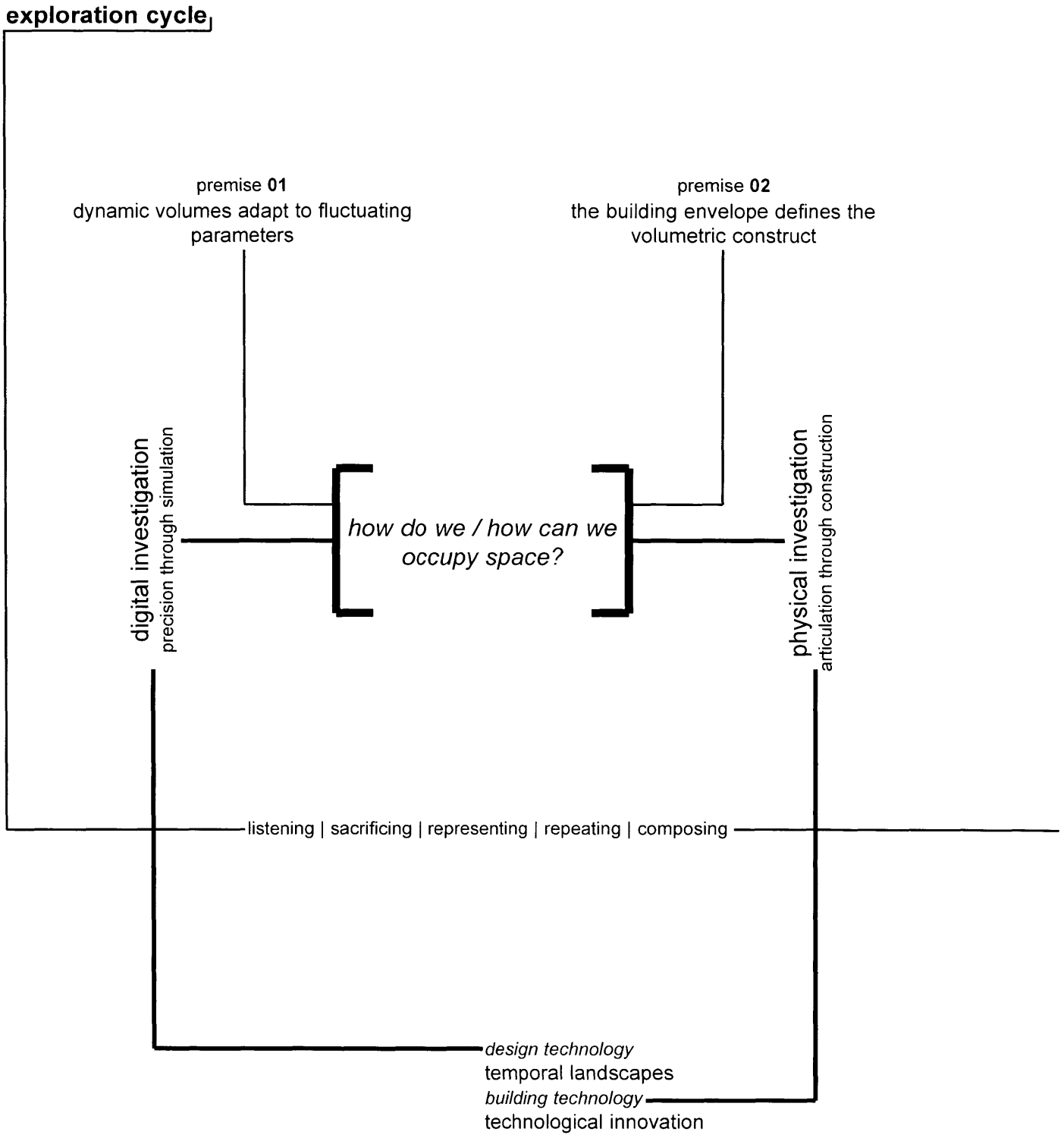
A B S T R A C T

Research into the creation of a Variable Volume Architecture is explored through a series of proposals and projects. An argument is established to develop the means and methods of achieving an architecture of transformation. The basis for developing such a stance is substantiated and clarified with the act of probing into constructs of various scales.

The design and manufacturing of a full scale prototype is explored to bring bearing on the physical resolution of the proposal. The device is an acknowledgement of potential applications and uses. The material, spatial, and structural nature of the propositions are articulated and examined throughout the investigation. The morphology of the concepts presented is derived to bring clarity to issues towards an endeavor for creating a responsive architectural landscape.

Thesis Supervisor: John Fernandez
Assistant Professor of Building Technology
Massachusetts Institute of Technology

CONTENTS


exploration cycle
premise 01
dynamic volumes adapt to fluctuating parameters
premise 02
the building envelope defines the volumetric construct
digital investigation
precision through simulation
how do we / how can we occupy space?
physical investigation
articulation through construction
listening | sacrificing | representing | repeating | composing
design technology
temporal landscapes
building technology
technological innovation

Introduction | Platform

The making of spatial propositions has a great impact on the inhabitable environment. As our surroundings are built, shelter is created both physically and socially. The construction of space and its use is regulated by the life span of occupation. Volumes are continuously either renovated, reprogrammed, or torn down. These acts place substantial demand on the boundary condition. The enclosure that defines occupation is an important interface that initiates the act of making architecture.

"We shape our buildings, and afterwards our buildings shape us."[1] If Winston Churchill's quote is modified, one could imagine a world in which we shape our buildings; thereafter, our buildings adapt to change, and thus we again have shaped our buildings. Looking at it from this viewpoint allows one to see that a causal loop can be formed that feeds back into the development of our spaces. The process of imaging this loop is also instrumental in the method of researching the 'dynamic occupation' concept. Flexibility creates opportunities for unique spatial paradigms to exist. The built environment should allow for manipulation as internal and external circumstances change.

Figure 001:
Inquiry Loop

The process of investigation is examined through a central question: how do we / how can we occupy space? This query is dissected on two fronts, digitally and physically. The process of conducting experiments is intertwined between these two parallel worlds. In the digital realm, visualization of ideas flows through a conduit that is based in a programmed environment. The physical realm brings

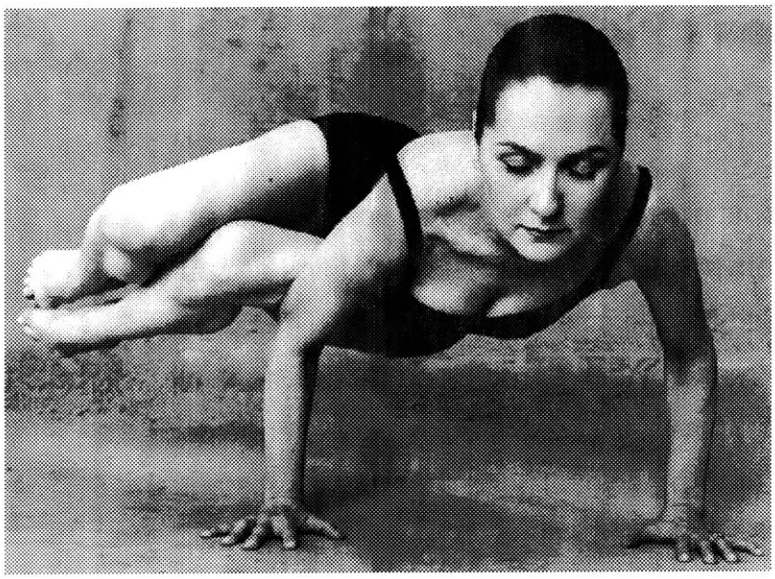


Figure 002:
Sharon Gannon showing strength, agility and balance in this side crow yoga pose

tactile and spatial truth to bearing. Through this act of discovery, a clarity is strived for in the relationship of form and space.

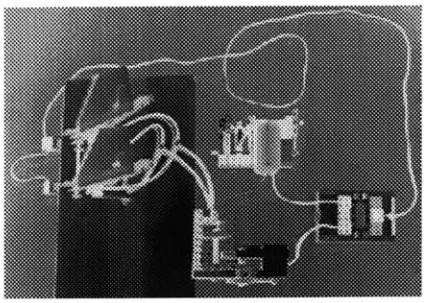
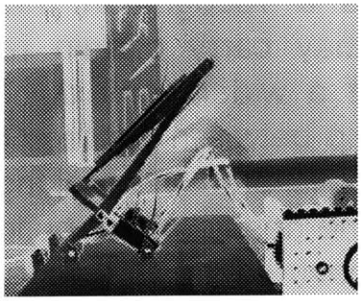
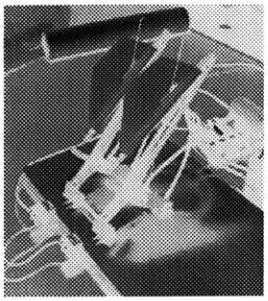
The basis for this investigation is the acknowledgement of the fact that living is a dynamic enterprise. With this premise, an architectural idea has been formulated to suggest space is sculpted with response to variable parameters. Architecture becomes a living entity, and as such must be adaptable. Using this framework, one realizes that movement is an essential component in building a research methodology.

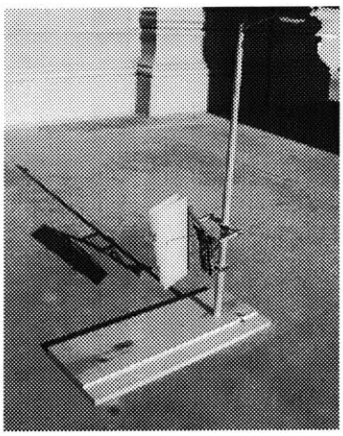
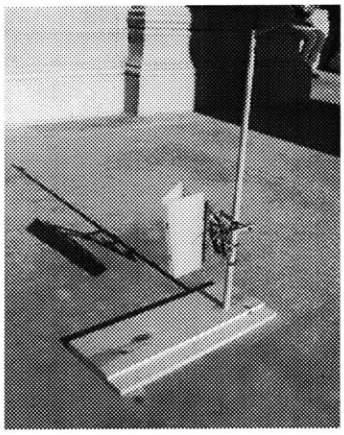
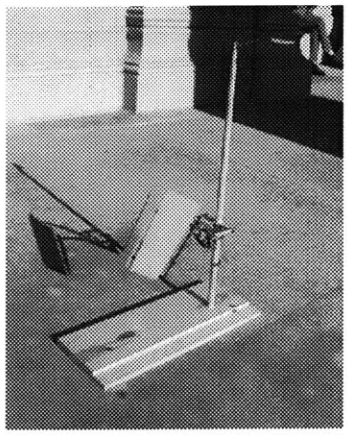
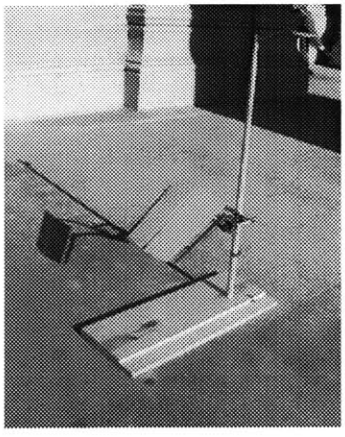
The understanding that building detail may be found within the architectural strategy, and that strategy may be found in the details, is a recognition that a building may carry certain resonances of a wider context. The relationship between strategy and detail necessitates the making of rules for the design of the building and its construction. These rules act as data against which to measure the appropriateness of the detail and also sustain the strategy. They are a way of releasing our intuition so that new judgments born of the experience of building can be explored.[2]

-Peter Salter

Listening

1

KINETIC

The following six projects introduced in this chapter outline and define avenues of exploration. These projects are explained to shed light on a trajectory that is mapped out in the research agenda of the subsequent chapters.

[intelligent kinetic systems]

The exploration into moving spatial systems ignited the research towards an adaptable architecture. The design of kinetic systems and devices is created to allow for transformations to occur. The tools necessary for creating this work are based in a world of precision. Digital software and computer controlled hardware are at the heart of designing movement.

Figure 003: Project 001-plan view
Figure 004: Project 001-collapsed position
Figure 005: Project 001-collapsed position
Figure 006: Project 001-expanded position

LEGO brick: a CPU that is programmable through software and provided in the LEGO Mindstorm Kits

Developed in Project 001 is a mechanism that transforms from a vertical plane to a horizontal plane. Activated via occupation, the individual units open themselves to provide shelter when required. The unit works with one swift movement of a pneumatic piston that is activated through a touch sensor. The LEGO 'brick' is programmed to check for sensor activities and to control the motor's operation. The steel rod acts as a guide to the moving surface and also aids in the transmission of uplift forces. The device acknowledges the idea that the making of a physical artifact is not only designed and constructed but also programmed to conditional parameters.

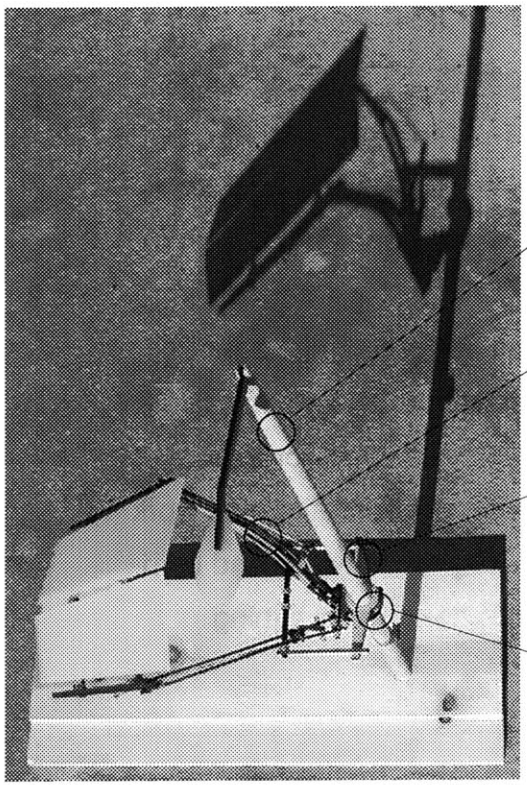
Figure 007: Project 002-collapsed position

Figure 008: Project 002-partially expanded

Figure 009: Project 002-partially expanded

Figure 010: Project 002-expansion complete

Further exploration towards a responsive apparatus is conducted in Project 002. The device constructs a transformation that expands into a three dimensional state. Taking advantage of existing urban infrastructure, the kinetic canopy clings onto a light pole as its source of primary structure and electricity. Activated dependent upon occupa-

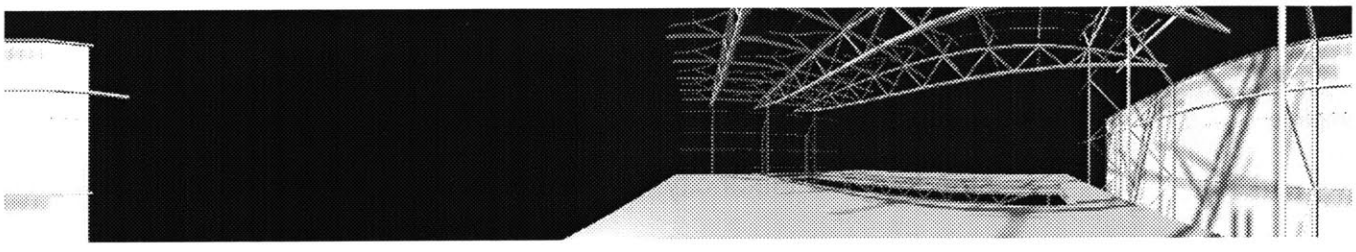


[standard urban infrastructure: light post

[main support arm and tension rod: sliding opening within arm to expand device

[bracket support: attached to light post

[control ring: the sliding of this component up and down along the light post expands and collapses the device



transformation: the process of change in form from one static state to another[4]

Figure 011:
Project 002-plan view

tion and environmental conditions, the mechanism transforms from a flat two-dimensional plane to a three-dimensional spatial structure. The arms are designed to efficiently transfer structural loads to the light post once fully opened. The arms retain structural integrity in both axes during the entire transformation. Springs are employed to stabilize movement of uplift forces transmitted through the tension rods. An instance of a smaller scale kinetic system with a larger one. The ability of the canopy to transform dependent on various conditions not only provides a dynamic urban intervention, but also starts to suggest a direction for the making of an adaptable architecture.

As the tools and methods of creating kinetic forms become intertwined within the design process, one gains greater control of the spatial manipulations. The importance of constructing a digital and physical process in unison is necessary in developing the desired apparatus. Making the shift to a larger scale adds another level of complexity that is ideally solved through collaboration.

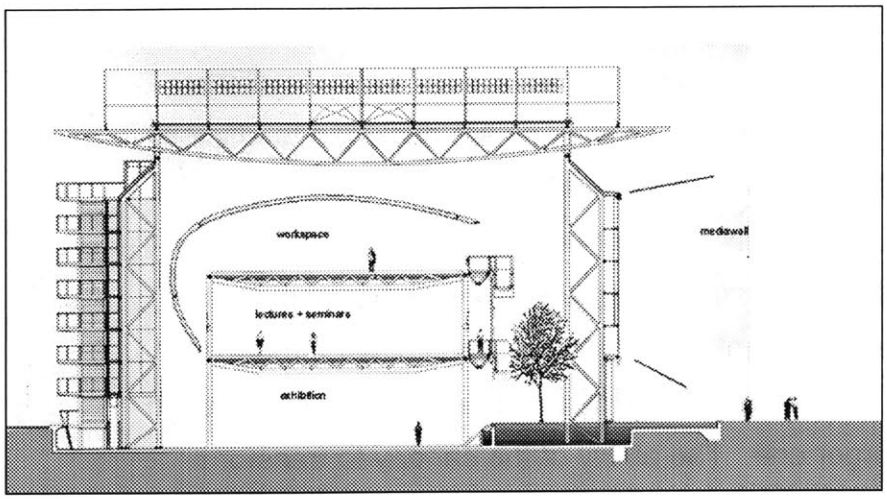
[architect + engineer: collaborations and explorations]

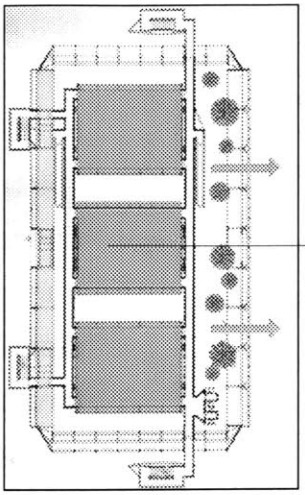
ENGINEER

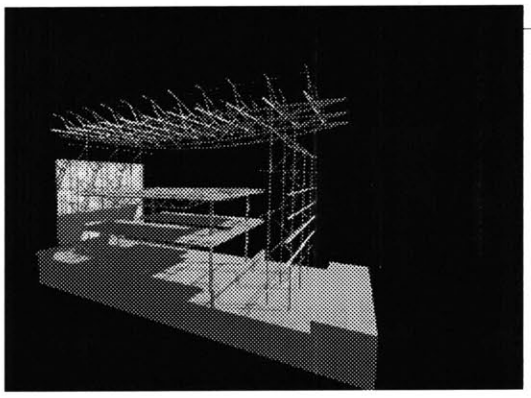
The making of architecture is not an isolated process. Many disciplines are involved in the conception and construction of a building. As Otto Wagner preaches:

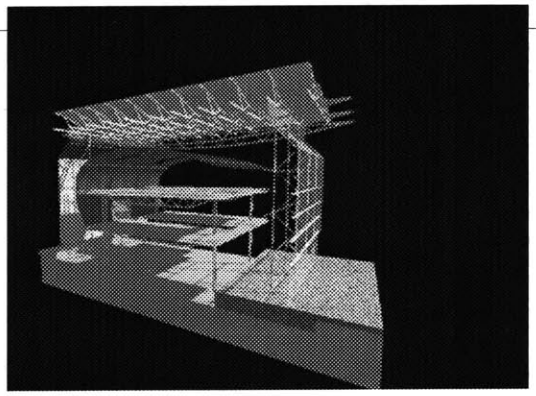
> The engineer who does not consider the nascent art-form but only the structural calculation and the expense will therefore speak a language unsympathetic to man, while on the other hand, the architect's mode of expression will remain unintelligible if in the creation of the art-form he does not start from construction.[3]

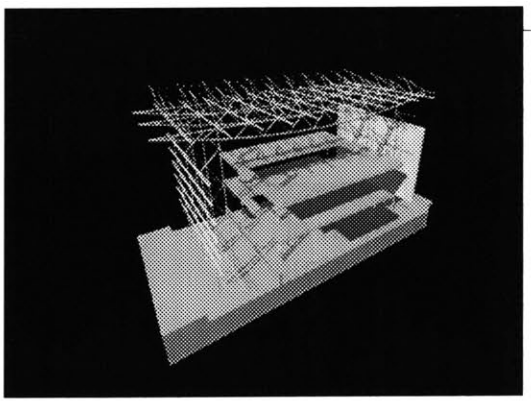
Figure 012:
Project 003-flattened 360 degree view of project


workspace
mediawall
lectures + seminars
exhibition









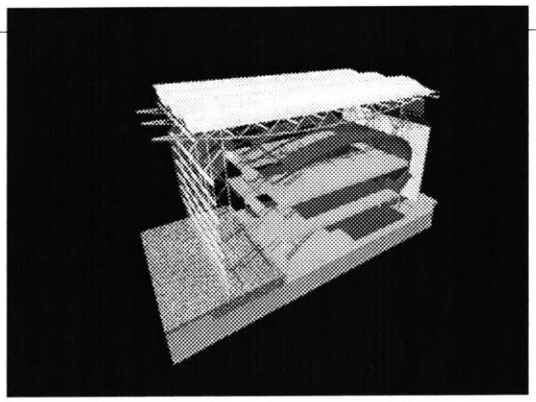


Figure 013:
Project 003-section view

Figure 014:
Project 003-plan view

Engineers play a critical role in providing calculated scope and direction towards a realized project. The proposal that follows is developed through a dialogue with engineers from the firm Ove Arup and Partners, London.

Fostering collaboration between architects and engineers, Project 003 explores the reconstruction of a temporary building. The investigation revolves around the 1992 British Pavilion for the Seville Expo designed by Grimshaw and Partners. The fictional proposal is to reconstruct the structure in London on the shore of the River Thames. The main concern developed in the relocation concept is the shift of climate and its impact.

The London climate is dealt with through a series of site specific decisions, spatial concepts and material investigations. The structure is oriented with the long axis running north-south. The glazed facade on the west side receives the greater amount of solar gain during the winter time. The roof fins, in its prior application, are designed to provide shade to the roof surface. In the relocated proposition, the profile of the roof is reinterpreted as light scoops to allow for as much light as possible in overcast situations.

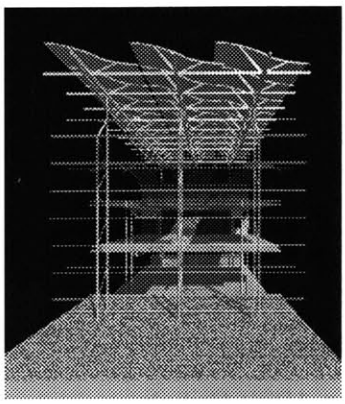
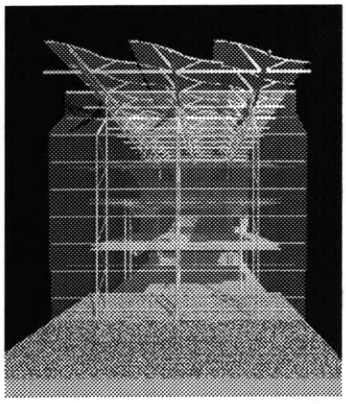
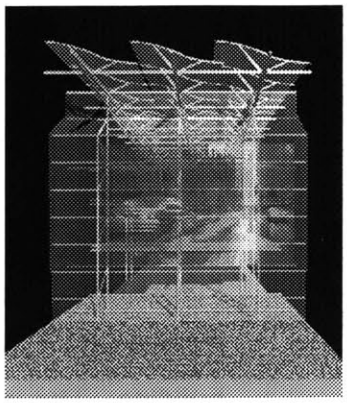
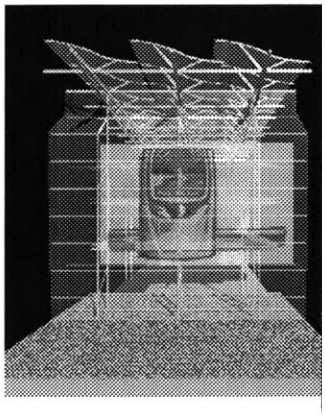
Figure 015:
Project 003-rendering of structure

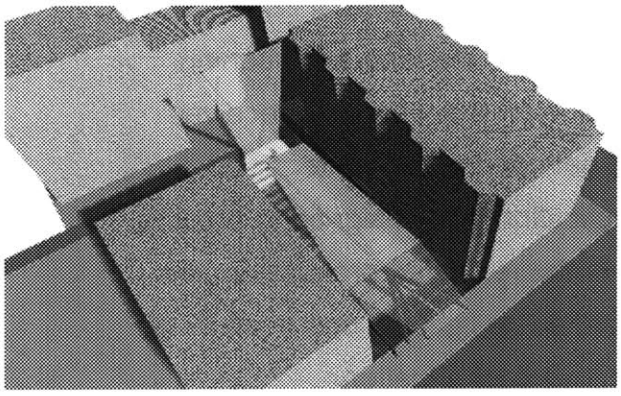
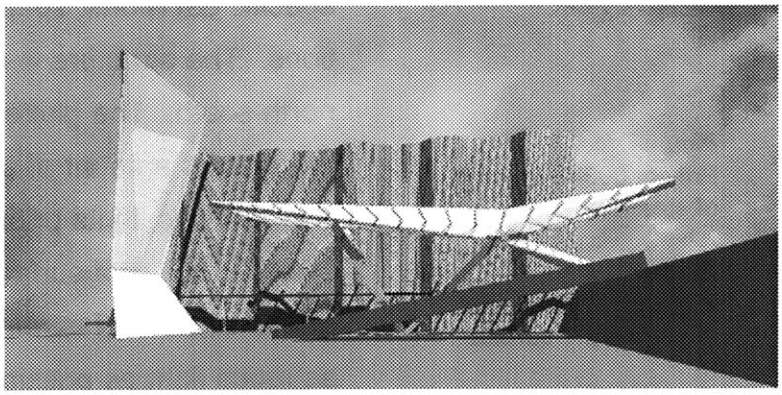
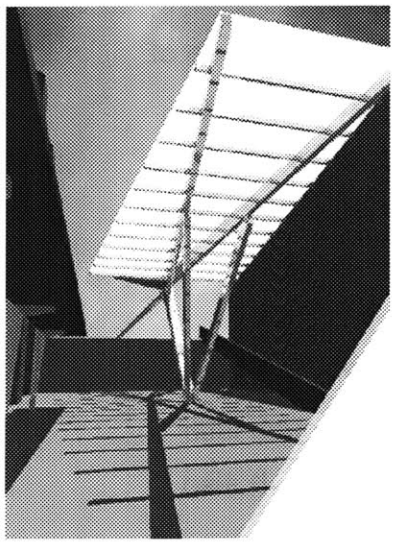
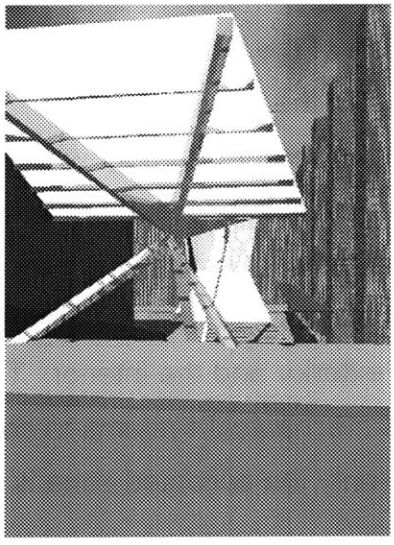
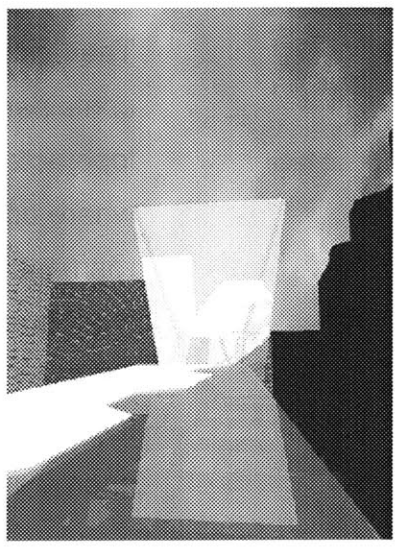
Figure 016:
Project 003-rendering of structure + surface

Figure 017:
Project 003-rendering of structure

Figure 018:
Project 003-rendering of structure + surface

The occupation of the building is layered through the use of containers within the larger envelope. The exterior envelope acts as the weather barrier, while the interior space, where occupation is intensified, provides a climatized environment. The residual space is not conditioned with mechanical systems, but acts as a transitional climate between the exterior and the interior. This concept allows the building's mechanical systems to consume much less energy since only the occupied zone is controlled. It also

allows the occupants to pass through a threshold condition before entering the hermetically enclosed space.

Figure 019:
Project 003-electro-chromic glass, clear view
Figure 020:
Project 003-electro-chromic glass, frosted
Figure 021:
Project 003-electro-chromic glass, with projection
Figure 022:
Project 003-electro-chromic glass, with projection

Within the framework for creating a permanent structure, the material on all four elevations had to be reconsidered. The original circumstances of the pavilion allowed for the north and south facades to be clad in cloth. With the new location, the north and south facades have been reclad with ETFE cushions. A tough plastic that has a life span greater than twenty years, this material allows for a highly insulative solution while still allowing light to pass through the boundary condition. The cushions thickness is variable through the control of the amount of air between the interior and exterior layers.

The west facade originally had a glass wall with recirculated water running down it to achieve a cooling affect in Seville. The new facade is designed using electro-chromic glass. The glass allows varying opacities that can control the amount of light entering the volume. The controlled change in opacity would also allow for visual projections on to this surface.

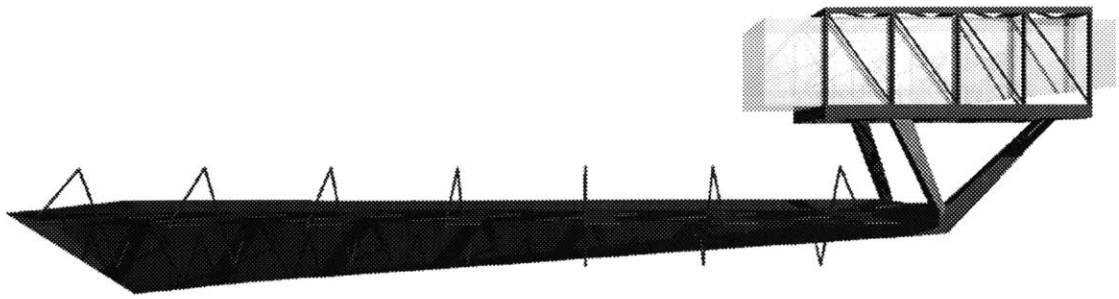
The ideas manifest in Project 003 have been through collaboration and negotiation with the engineers involved. The integration of these disciplines within the design process allow for experimental ideas to become physically realities.

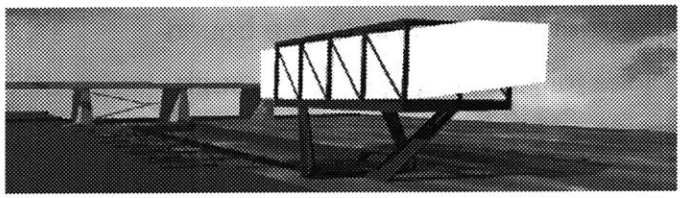
[generative structural morphologies]

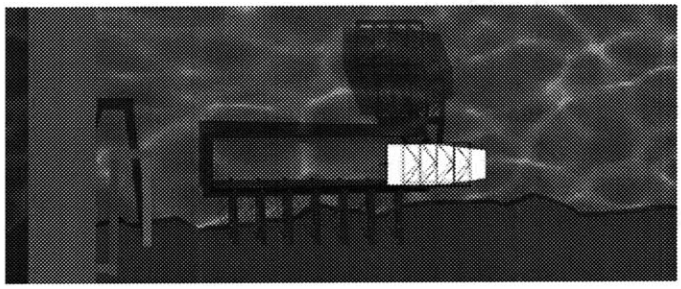
Figure 023:
Project 004
Figure 024:
Project 004
Figure 025:
Project 004
Figure 026:
Project 004
Figure 027:
Project 004

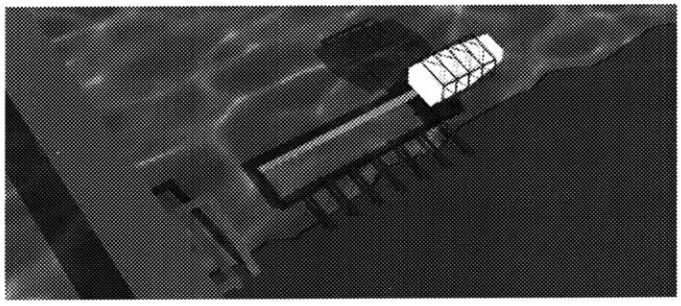
STRUCTURE

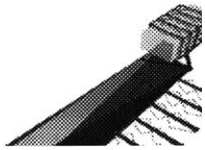
The making of volumetric constructs is directly integrated to the development of a structural direction. Architecture cannot be conceived without structure making their relationship

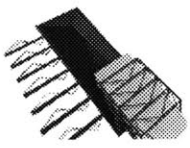












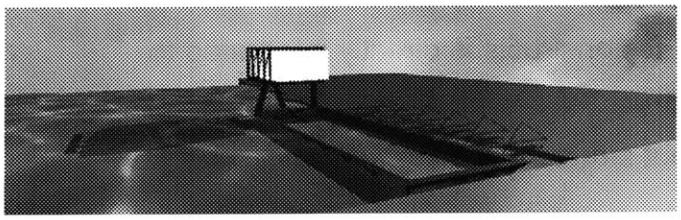


Figure 028:
Project 005-elevation

Figure 029:
Project 005-perspective

Figure 030:
Project 005-perspective

Figure 031:
Project 005-perspective

Figure 032:
Project 005-perspective

Figure 033:
Project 005-detail

Figure 034:
Project 005-detail

Figure 035:
Project 005-detail

Figure 036:
Project 005-aerial view

Figure 037:
Project 005-aerial view

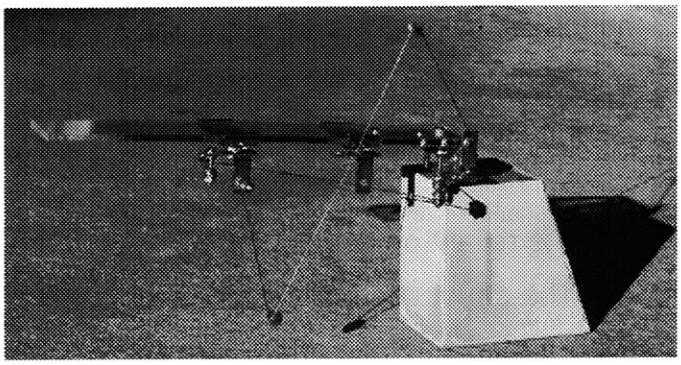
Figure 038:
Project 005-bottom

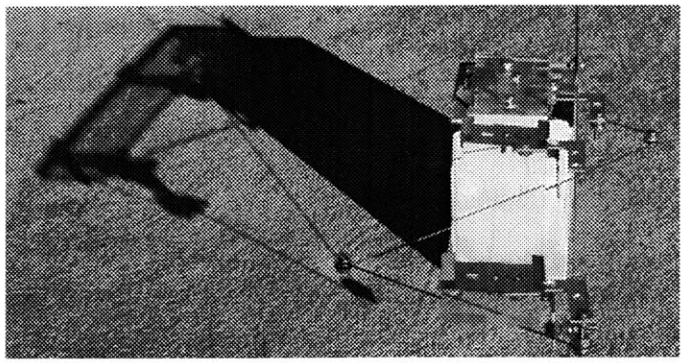
inseparable and co-dependent. Beginning with a structural attitude towards a programmatic situation, one can ground the design within a physical framework.

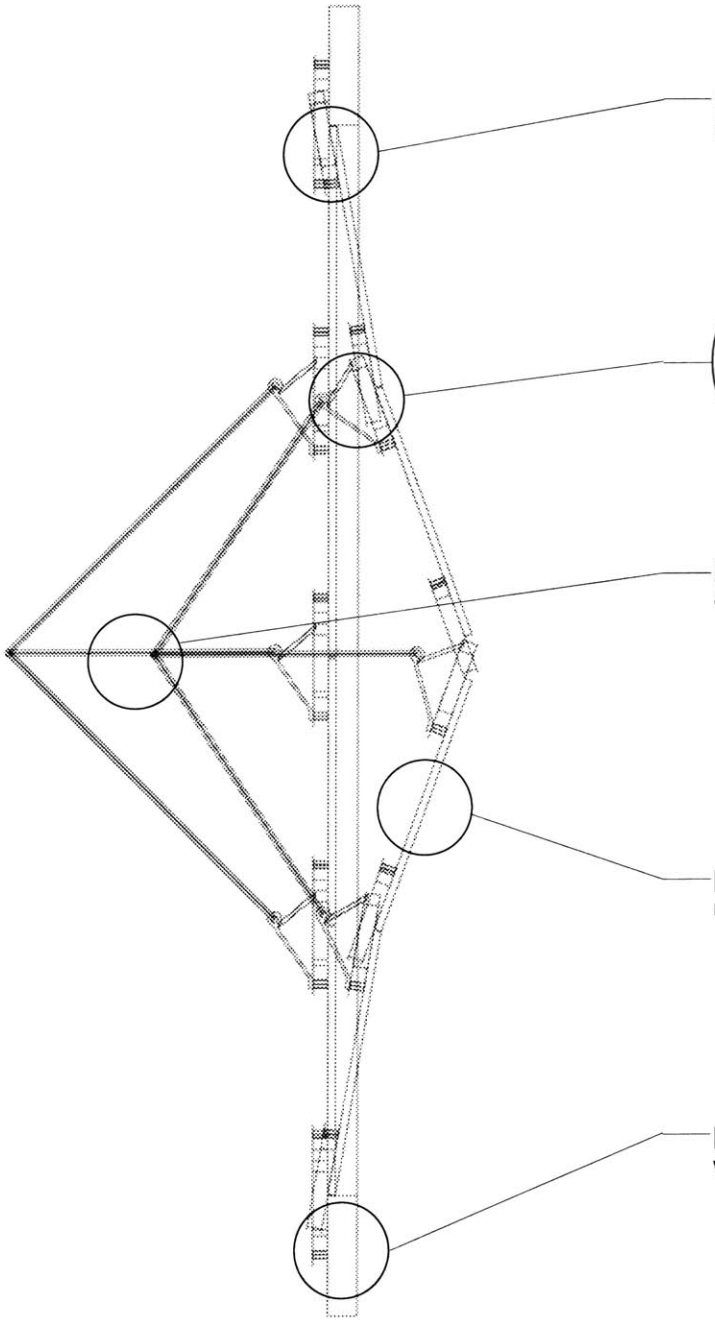
The conception of Project 004 is reliant on developing a structural base morphology. The structures are designed to function in tandem in creating a market, plaza and cinema. The structure is formed to allow the volume that is contained to be manipulated. The large roof fin has supports that triangulate the loads to the base and provides basic shelter. To change the cantilever condition of the horizontal wing, the struts are able to pivot at their base and brace the main beams . By employing these mobile struts, the volume of the space can be manipulated. The two wings together provide the framework for the temporal programmatic nature of the site.

The dynamics of occupation and program are an integral part of Project 005. An experiment to understand the nature of structural members placed in water acted as catalyst to the project. The members are frozen and then thawed to observe dynamic behavior between the support condition and its morphing foundation. With this experiment in hand, the project is developed.

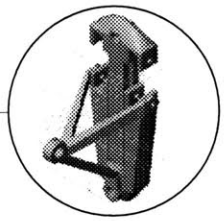
The three states of the material (solid, liquid and gas) are interpreted into a program. The ice rink, pool, and sauna reside in a vessel that is docked on the Charles River in Boston. The concept is to allow the change in climate to affect the program of the proposal. The winter program brings on a frozen condition and thus activates the ice rink. The stability of the vessel is achieved in different ways in the longitudinal and short axes. The profile of the vessel in







[hinge mechanism: no bracket required at frame condition



[activation truss: location of applied force to activate system displacement

[panel: surface that is manipulated through the rotation of the hinge

[frame: dimensionally controlled opening in which system is attached to

Figure 039:
Project 005-bridge connection

Figure 040:
Project 005-bridge connection

section is created to force the deep end of the pool to sink. The liquid (water) plays an important role in providing the weight necessary for this to occur. The main volume employs a double-hull system allowing for the vessel to float. The steel ribs between the hulls are profiled to provide the support necessary and to create an air space.

Stability in the short direction is achieved by the use of a series of bridges that link the vessel to the shore. These bridges have a glide mechanism that allow for a controlled sway of the vessel to achieve equilibrium. The process of designing is directly dependent on the act of achieving balance. Project 005 demonstrates the potential of structure in creating spatial, programmatic and physical constructs.

Structural insights gained into the act of creating equilibrium suggest a manner in which flexible non-fixed systems can be achieved. Coupling this research with a kinetic design process leads to the integration of structure and movement.

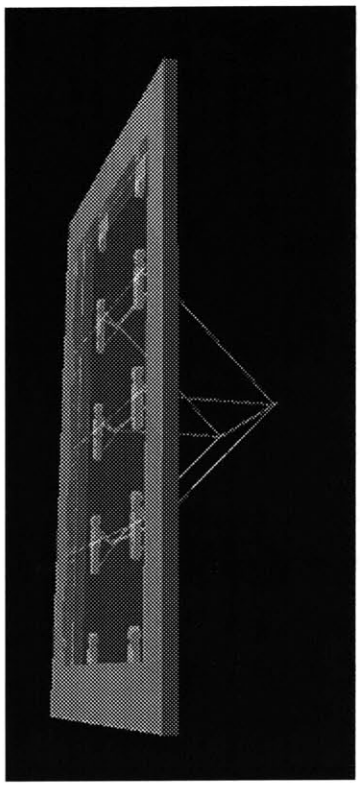
[computer aided design / computer aided manufacturing]

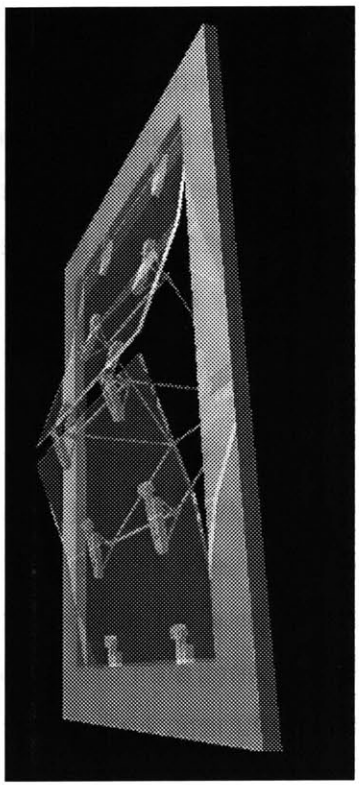
Figure 041:
Project 006-section

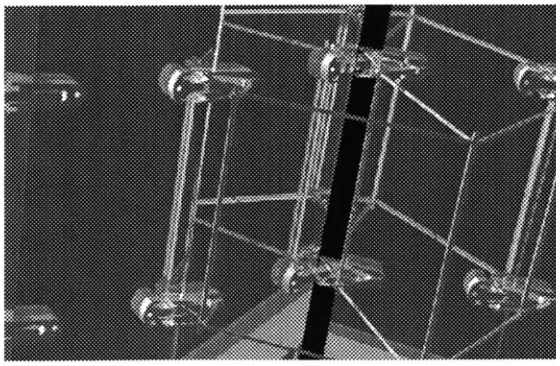
SKIN

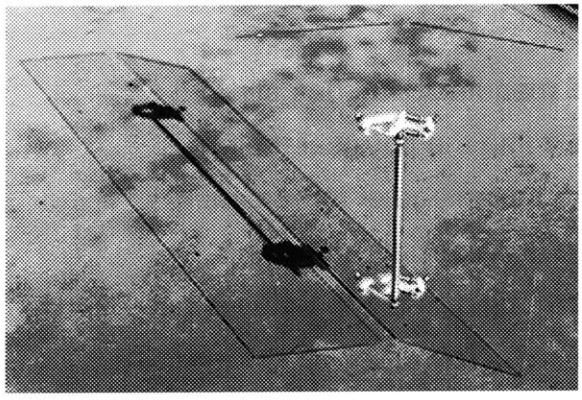
The advent of computer-aided manufacturing has allowed for the transfer of digital models into the physical realm. Project 006 is designed to take advantage of three-dimensional plotting technology to design specialized components. The design of the a fluctuating skin apparatus is initiated with this technology in mind. The proposal is for a single layer system that expands and contracts with control and movement residing at the joints.

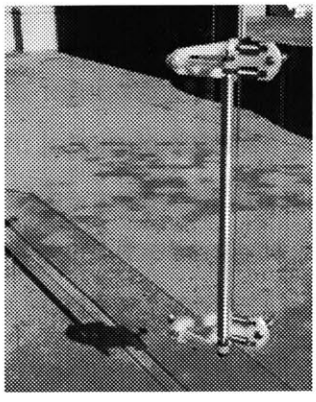
The design of a hinge mechanism is initially explored in the digital medium. The idea is to allow volumetric manipula-

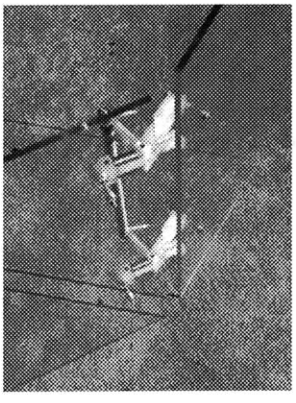












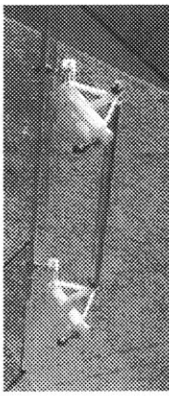


Figure 042:
Project 006-flat position

Figure 043:
Project 006-expanded position

Figure 044:
Project 006-truss detail

tion and varying porosity of the surface condition. Activation of the assembly is achieved through a secondary truss. With variation in force and magnitude, the expansion of the panels is provoked. The hinge has been explored through several iterations to its current state of refinement. The idea is to allow the three dimensional bracket to be attached when required. The truss that has been created distributes the force to the joints to create the expansion. Rotation within the truss system is required to change the direction of the forces applied.

There are five components that make up the hinge. Two of the components are designed to slide within each other while accommodating the two springs. The hinge is anchored to the surface (glass or metal) through the use of guided bolts. The mechanism works by pivoting and sliding along two axes. The sliding action allows the attached panels to increase the dimension of separation. The springs within the joints allow the system to contract and return to a taut position.

Figure 045:
Project 006-prototype

Figure 046:
Project 006-prototype

Figure 047:
Project 006-prototype

Figure 048:
Project 006-prototype

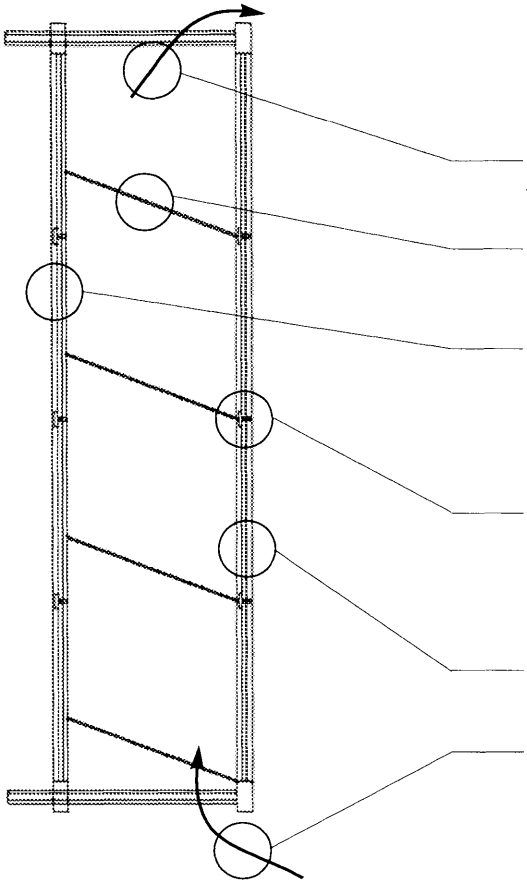
The system can be imagined at various scales. The amount of usable volume could be controlled by the necessity of occupation. The system allows the volume to be expanded while at the same time dissolving the barrier between two zones. The edge becomes a reconfigurable surface, where opportunities for response to various conditions are resolved.

The skin has to be like the pelt of an animal, capable of changing according to the seasons. It must also respond with the accuracy of instinct to the diurnal and annual changes of circumstance. Only by layering can it attempt so much. Each component of the layered skin is used to reinforce a component of the space or circumstance: each layer is a commitment to the generosity of the space.[5]

-Peter Salter

Sacrificing

2



[exhaust air: movement of warm air out of interstitial space through opening at the top of the system

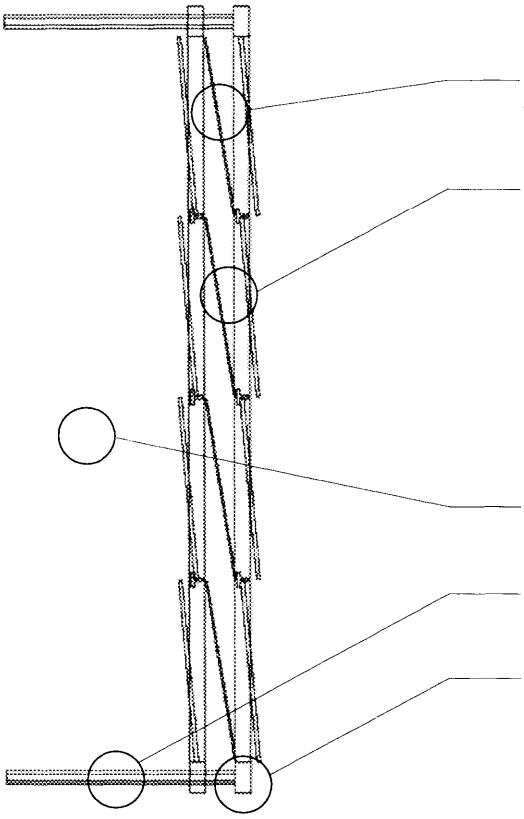
[interstitial panel: rigid surface with variable positioning opportunities acting as light baffle and view control

[interior panel: placed within frame, illustrated as a glass panel

[hinge joint: point at which interstitial panel is hinged from, part of frame for external panels

[exterior panel: placed within frame, illustrated as a glass panel

[intake air: movement of cool air into interstitial space through opening at the bottom of the system



[interstitial panel: in closed position, falling in vertical alignment with exterior and internal panels

[internal depth: interstitial volume is collapsed thus reducing the depth between the external and internal surfaces

[internal volume: increase in space due to system in flat position

[tubular guides: internal frame slides along members attached to building structure

[external frame: fixed at the end of the tubular guides

FLUCTUATION

The building envelope system can be as heavy and solid as stone or as light as paper. This variation is dependent upon program and use. The underlying principle taken in this investigation is to envision the envelope system as a permanent and layered, yet dynamic enclosure.

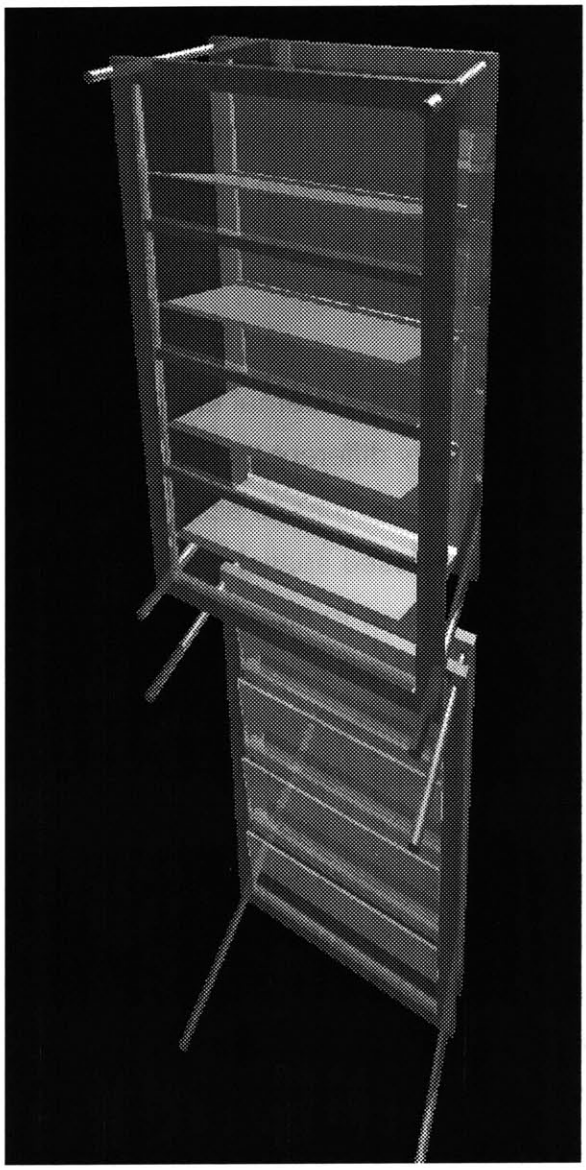
Building a dialogue between the external and internal environment is essential. The concept is very different than creating hermetically sealed spaces. What one tries to achieve taking this avenue is to allow for the enclosed spatial proposition to be responsive. The skin is allowed to be reconfigured and manipulated. The connection between exterior and interior becomes intensified and made legible in the various forms that the envelope / apparatus may generate.

Double skin building envelopes are designed to create a barrier to the external environment through the creation of an interstitial space. The depth between the exterior and the interior layers is used to control the climate of the interior. The vertical space produces a stack effect in which warm air may be exhausted in the summer while being contained and trapped during the winter.

Figure 049:
Proposal 001-expanded section

Figure 050:
Proposal 001-collapsed section

Using this strategy, Proposal 001 demonstrates a system with double-skin facade characteristics. The difference in this system is one of variable depth. The dimension between the exterior and interior layer is variable and thus allows for a modified air flow condition. The space between also has a light baffle panel that changes its orientation dependent upon the width of the system.



THERMAL

Figure 051:
Proposal 001

The module has been designed to take into consideration thermal variation. The main concept of this idea is to allow the thermal resistance of the exterior barrier to vary. In a fixed facade condition the building envelope is built under the pretense that a certain thermal rating will be achieved. This thermal rating is static, and thus deals with year round conditions with a uniform performance level.

Proposal 001's internal dimension is designed to fluctuate between a 'thick' to 'thin' threshold condition. This ability allows the system to deal with thermal loads dependent upon climactic circumstances. A 'thick' threshold condition would create an interstitial volume allowing for the transfer of thermal loads from the exterior to the interior and vice versa. The inside and outside surfaces would open to allow for fresh air to enter the interior space. The 'thin' threshold condition would become a tighter configuration denying contact to the external climate and increasing the insulative value of the assembly. The zone could be filled with an insulative material (i.e. aerogel) to further increase its thermal rating. In the concept introduced, the actual performance of the system becomes dependent upon the position of the layers. This idea suggests that the system can be fine tuned to deal with the conditions at hand. A standard premise developed for building envelopes reads:

> Function of the Building Envelope: The building envelopes primary function is to separate the indoor environment from the outdoor environment. It cannot, in fact, act as an absolute separator, but, rather, it must restrict, to some degree, the transfer from one environment to the other of a number of environment constituents including the following:
> -heat energy by itself (including solar radia-

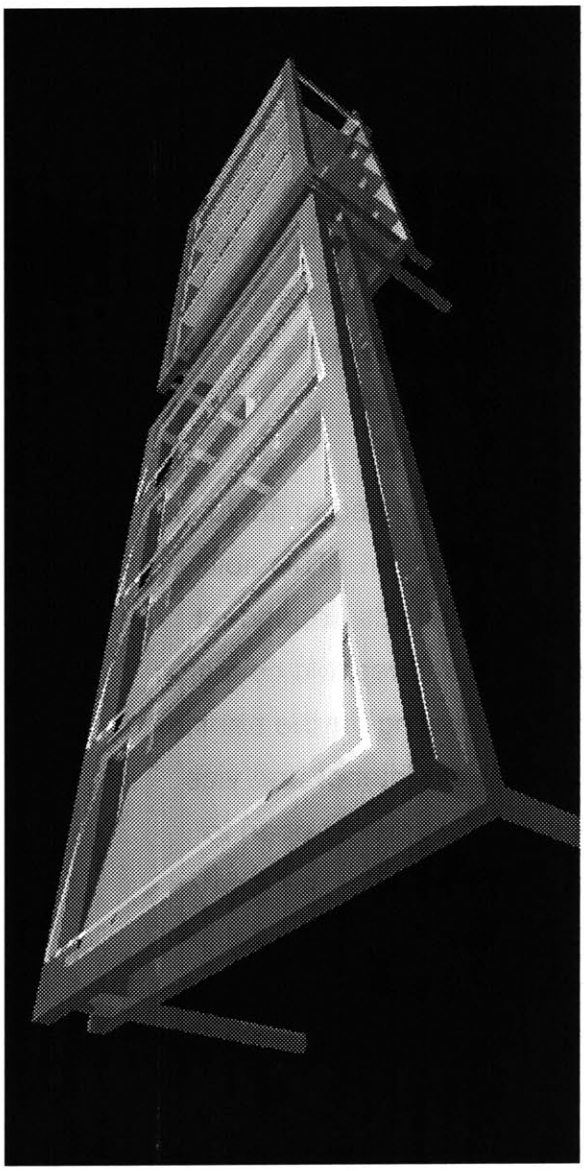


Figure 052:
Proposal 001

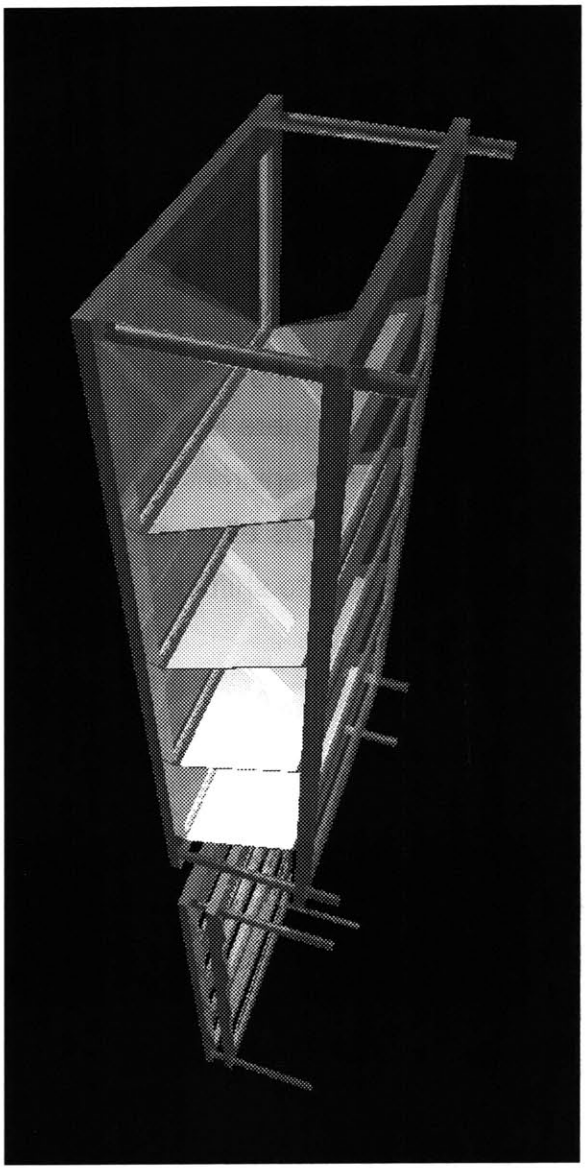
tion)
-air (and its attendant transfer of heat energy and water vapor)
-water vapor by itself (driven by vapor pressure)
-precipitation (driven by wind, gravity or capillary)[6]

The strategy outlined above by a national governing board contributes to the creation of buildings in which there is a disconnect between the interior and the exterior environments. Variable skin Proposal 001 moves towards eliminating a thermal disconnect by allowing the barrier to shift its thermal resistance properties.

VISUAL

A second concept that the proposal explores is the way in which natural light and view are controlled. The change in the lighting condition internally takes place as the assembly transforms. The horizontal fins in the extended condition act as light shelves bouncing light into the occupied space. The boundary also changes its visual connection to the exterior by reducing two planes into one. The internal panels act as a visual screen in the 'thin' position. The interior space is physically and visually connected to the exterior dependent upon the interstitial zone and its condition.

This method collapses the control of lighting into the building's infrastructure without adding a secondary system. The application of this concept is very much dependent upon the type of material that is used for the interstitial layer. The placing artificial lighting within this surface is also a possibility. The light would then act as a supplement to the interior lighting at night or to augment low light levels during the



day.

Figure 053:
Proposal 001

VOLUME

The interior and the interstitial volume have an inverse relationship. As the interstitial volume is reduced the interior volume is increased. The advantage of this fluctuation lies in the potential of reducing the building's energy consumption. Mechanical systems expend energy towards climatizing a given amount of volume. By reducing the internal volume during times of minimum occupation, the mechanical system has to deal with conditioning less space.

If the system is viewed as a large scale enterprise that clads an entire building, the incremental movement of the layers would add up to a large scale volumetric shift. Just 3" of movement on a 10 story building (floor to floor dimension of 9' and floor plate dimension of 50' x 50') would yield a reduction in volume by 4,478 cubic feet.

Proposal 001 creates variation in volume dependent upon which layer is static. In the case of the exterior layer being static, the system would allow for an increase in the internal volume by allowing the interior layer to move towards the exterior layer. If the interior layer is static, the volume being affected would be that of the the exterior.

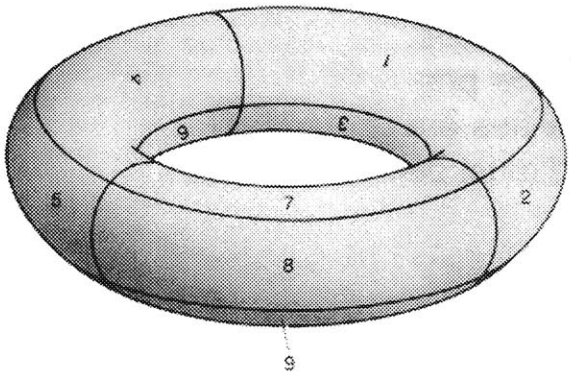
The variation achievable in this system is limited by the depth of the construction. The interstitial space in some cases could become large enough for occupation. This would result in boundary becoming a transitional zone similar to that in the exploration of Project 003.

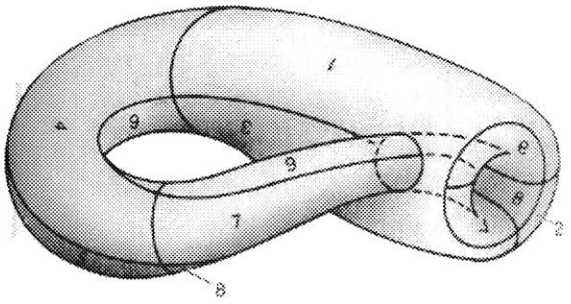
The threshold between two rooms - the room outside and the room inside - is like a filter mechanism that allows only certain prescribed qualities to pass from one room to the other. The threshold particularizes these qualities and reflects them in the fineness of the materials used in its construction. The resonance of the materials themselves relates the two spaces. The rooms change with the passage of the day, their qualities are dynamic, so the threshold must be adaptable.[7]

-Peter Salter

Representing

3


1
2
3
4
5
6
7
8
9


1
2
3
4
5
6
7
8
9

BLUR

The process of designing takes on an investigative route into geometrical manipulations and material properties. The role of the assembly is seen as a dynamic endeavor where material configuration and composition affect the barriers performance. The enclosed space becomes a transformative work that is stimulated and modified.

Figure 054: Torus

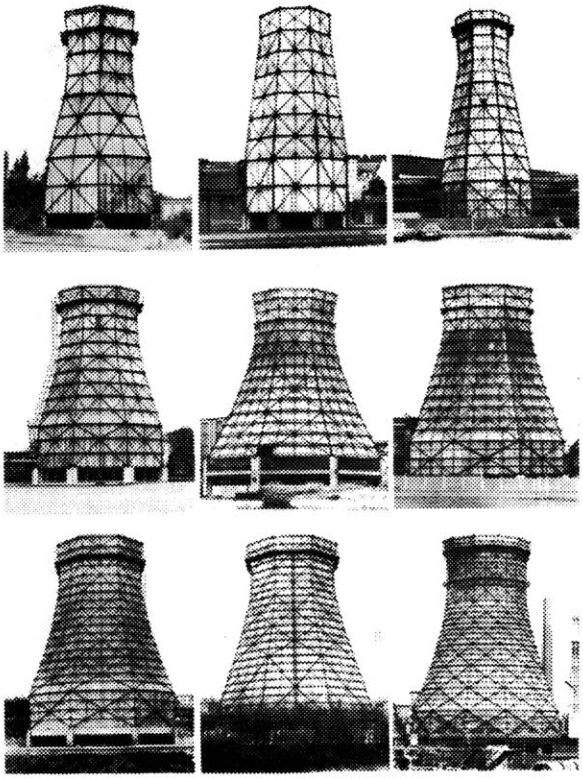
Figure 055: Klein bottle

The legibility of the system at moments can lead to inversions. For example, the form of a torus is clear with the relationship of inside and outside contained. Each surface of the form has a singular status that is fixed. While on the other hand, the Klein bottle creates an inversion. Dependent on where the surface is mapped, the possibility of alteration exists. Studies conducted by topologist sheds light on the reading of surfaces:

> "Topology studies the properties that remain unchanged when shapes are deformed by twisting or stretching or squeezing. Whether a shape is square or round, large or small, is irrelevant in topology, because stretching can change those properties. Topologists ask whether a shape is connected, whether it has holes, whether it is knotted. They imagine surfaces not just in the one-, two, and three-dimensional universes of Euclid, but in spaces of many dimensions, impossible to visualize."[8]

Internal and external become location dependent and the contortion of the form creates a blurred moment.

Spatial structures are defined through the framework that defines the edges. With the potential of variation at the boundary, a driving concept for Proposal 002 is given life. The model is seen as a flexible assembly within a static frame. The surface is allowed to be pinched without



destroying the stability of the system. As an important clue learned from early experiments in stability, the system is engaged and warped leading to geometric changes to create an expanded volumetric construct.

TYPOLOGY

The design of a system has been formulated through the development of a classification system. Classification systems have been used in grouping building types with similar functions. Differentiation of use and scale can be articulated through the development of a matrix.

Figure 056:
Bernd and Hilla Becher, photographs of cooling towers

Variable volume architecture is established as a category in which building envelopes have been mapped. The variable option has been broken down into three types: dynamic frame + static structure, dynamic frame + dynamic skin, and collapsible frame + static skin. These sub-divisions are useful to understand the territory in which responsive building systems can be developed within.

Figure 057:
Variable Volume Architecture Matrix
(next page)

Figure 058:
Variable Volume Building Envelope Systems Matrix
(next page)

Three built variations that exist are:

dynamic skin + static frame:

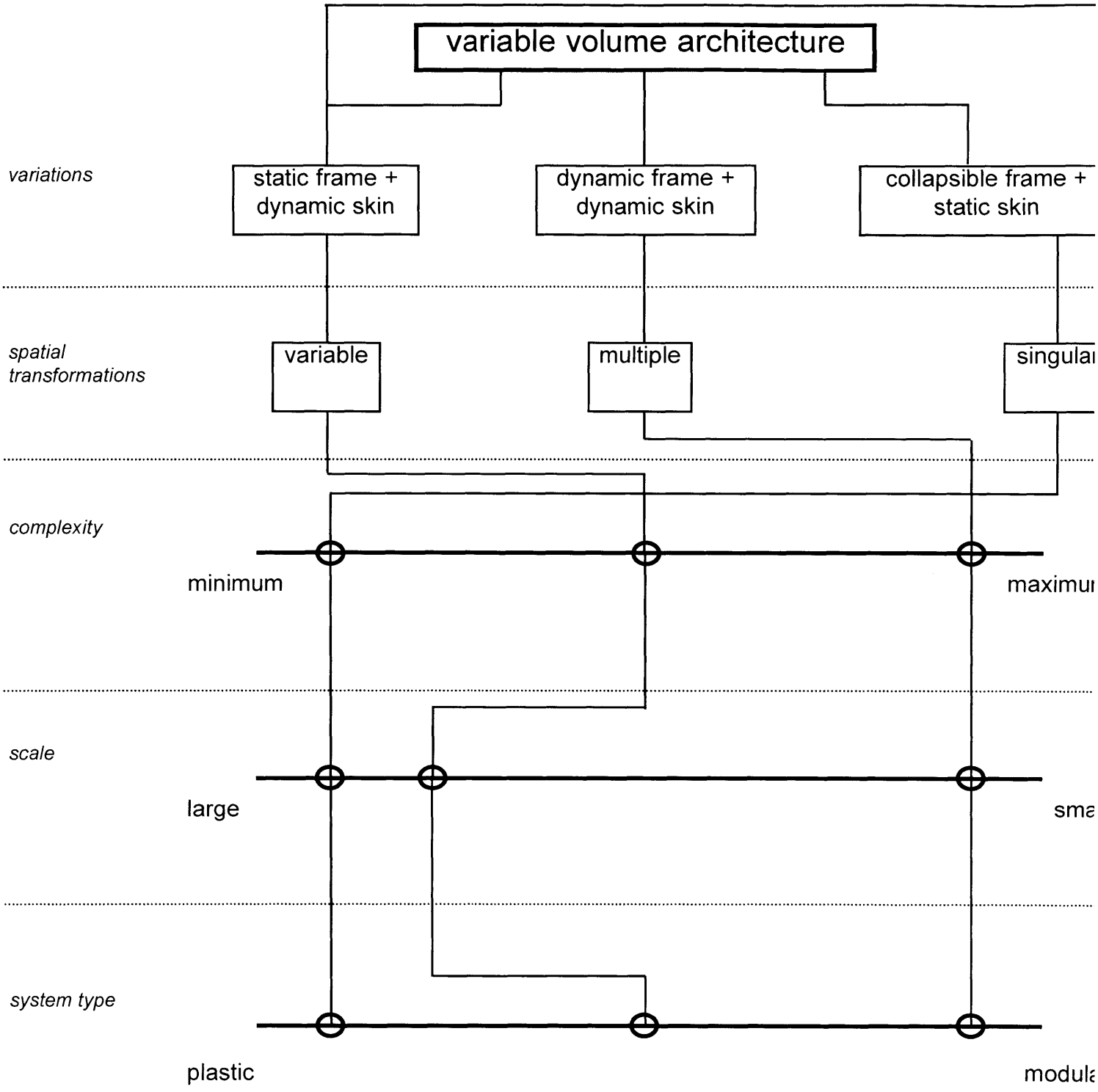
The Bauhaus Building; Architect: Walter Gropius

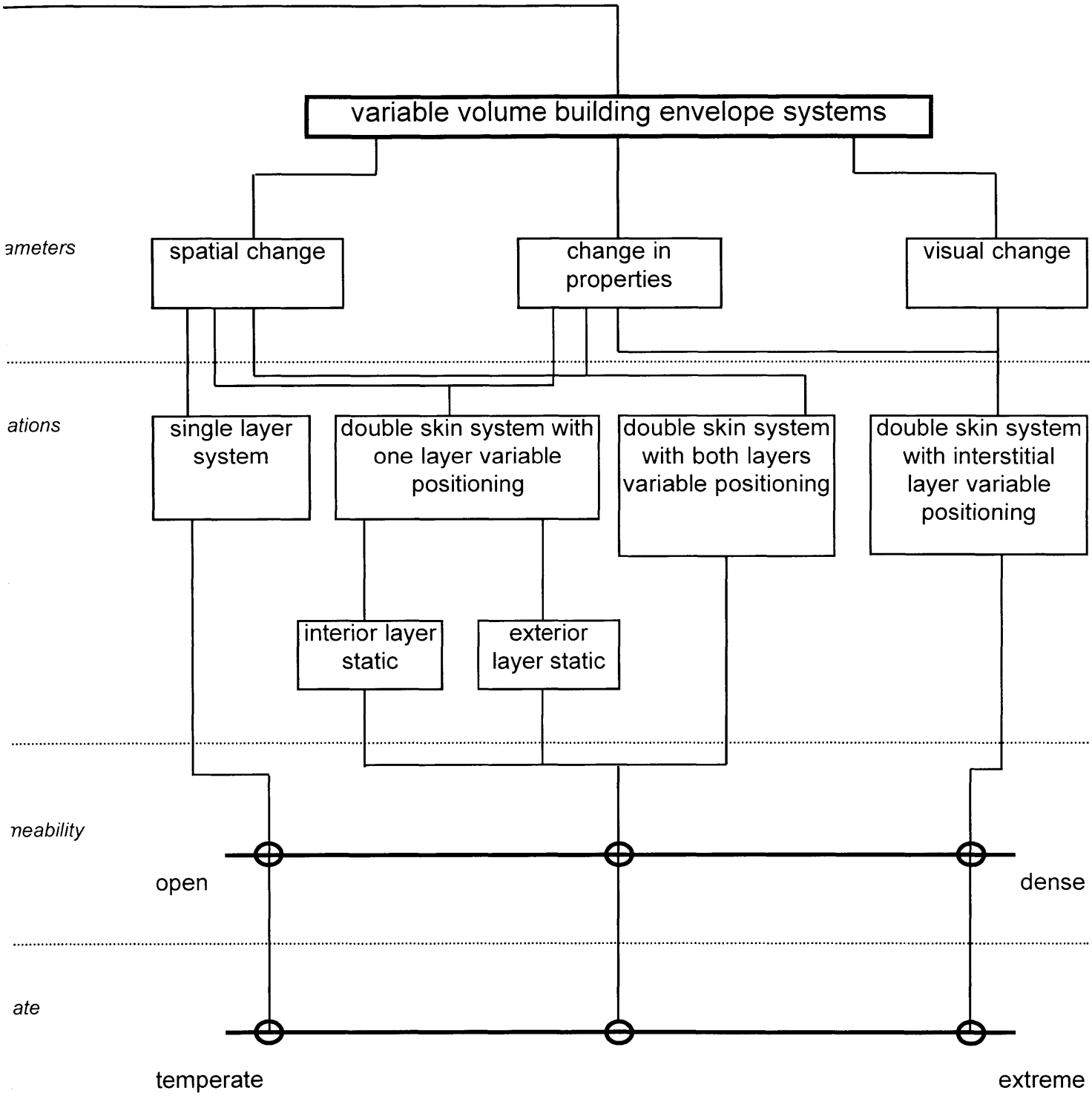
This envelope condition is a metal frame with a glass infill. The frame is attached to a static building structure. The glass within the frame is allowed to pivot, changing the profile and porosity of the external skin. The system is designed as a modular curtain wall.

dynamic skin + dynamic frame:

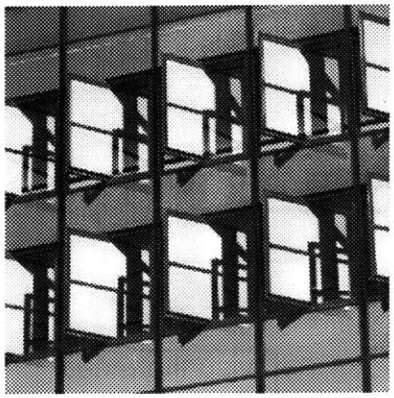
Airtecture Hall; Architect: Axel Thallemar

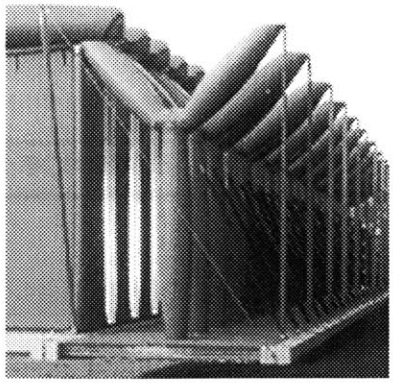
This building is erected through the use of air filled tubes. These tubes act as structure and skin of the building. The


variable volume architecture
variations
static frame + dynamic skin
dynamic frame + dynamic skin
collapsible frame + static skin
spatial transformations
variable
multiple
singular
complexity
minimum
maximum
scale
large
small
system type
plastic
modular


variable volume building envelope systems
ameters
spatial change
change in properties
visual change
ations
single layer system
double skin system with one layer variable positioning
double skin system with both layers variable positioning
double skin system with interstitial layer variable positioning
interior layer static
exterior layer static
neability
open
dense
ate
temperate
extreme

0043





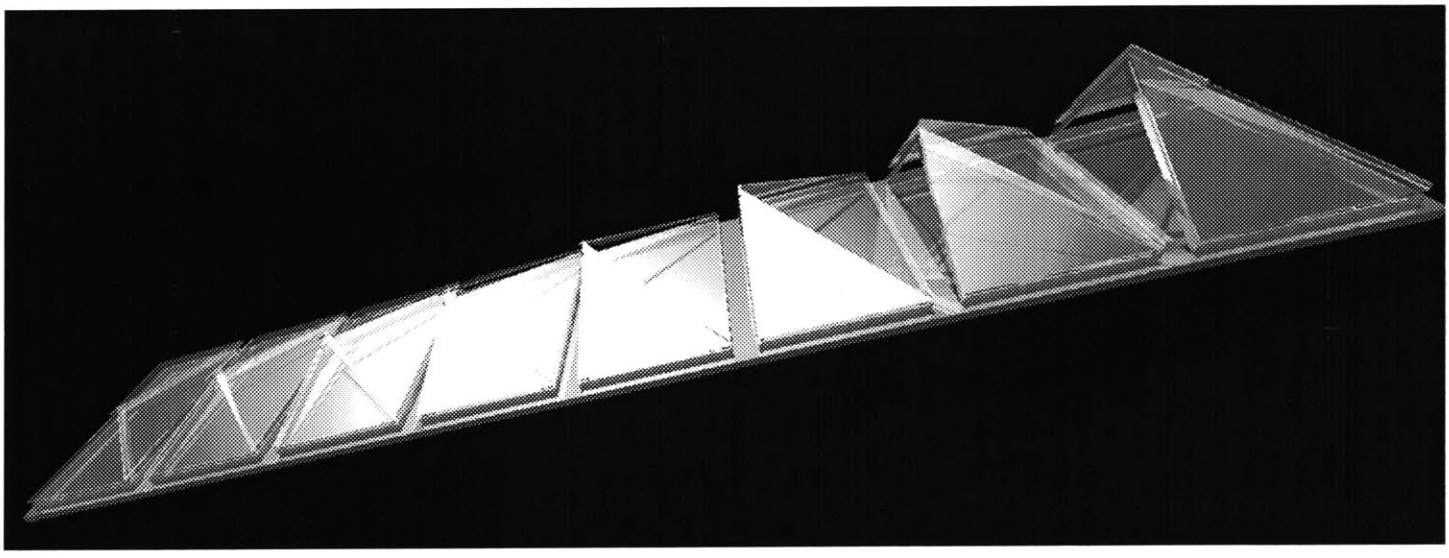


Figure 059:
Bauhaus Building

Figure 060:
Airtecture Hall

Figure 061:
IBM Traveling Pavilion

hall can be collapsed and relocated dependent on the time frame of use. The coupled relationship of skin and structure unifies the form of the building.

static skin + collapsible frame:

IBM Traveling Pavilion; Architect: Renzo Piano

The pavilion is designed to travel from city to city. The method of achieving a transition in location is through the careful articulation of creating a collapsible frame. Once the frame has been constructed and the skin is attached, the entire assembly becomes static.

Focusing in on the external envelope allows the matrix to be further fine-tuned. Detail has been added to the 'dynamic skin + static frame' category. The variations, from a single layer system to a triple layer system, allude to the permeability and climactic response achievable. The frame is seen as the primary structure for the building. The process of cladding the frame defines the spatial boundary. By constructing a flexible skin system, this boundary is allowed to change defined parameters: spatial, visual and thermal.

STABILITY

Figure 062:
Proposal 002

In reaching equilibrium between the external and internal environment, the components of the assembly maintain structural integrity. The two dimensional surface is transformed and broken through the process of movement. This fractured skin, becomes splayed physically to produce a three dimensional spatial structure. Through this manipulation, the planes that create the membrane begin to overlap and create gaps between the frame.

Analyzing the movement of the robotic warriors in 'Star

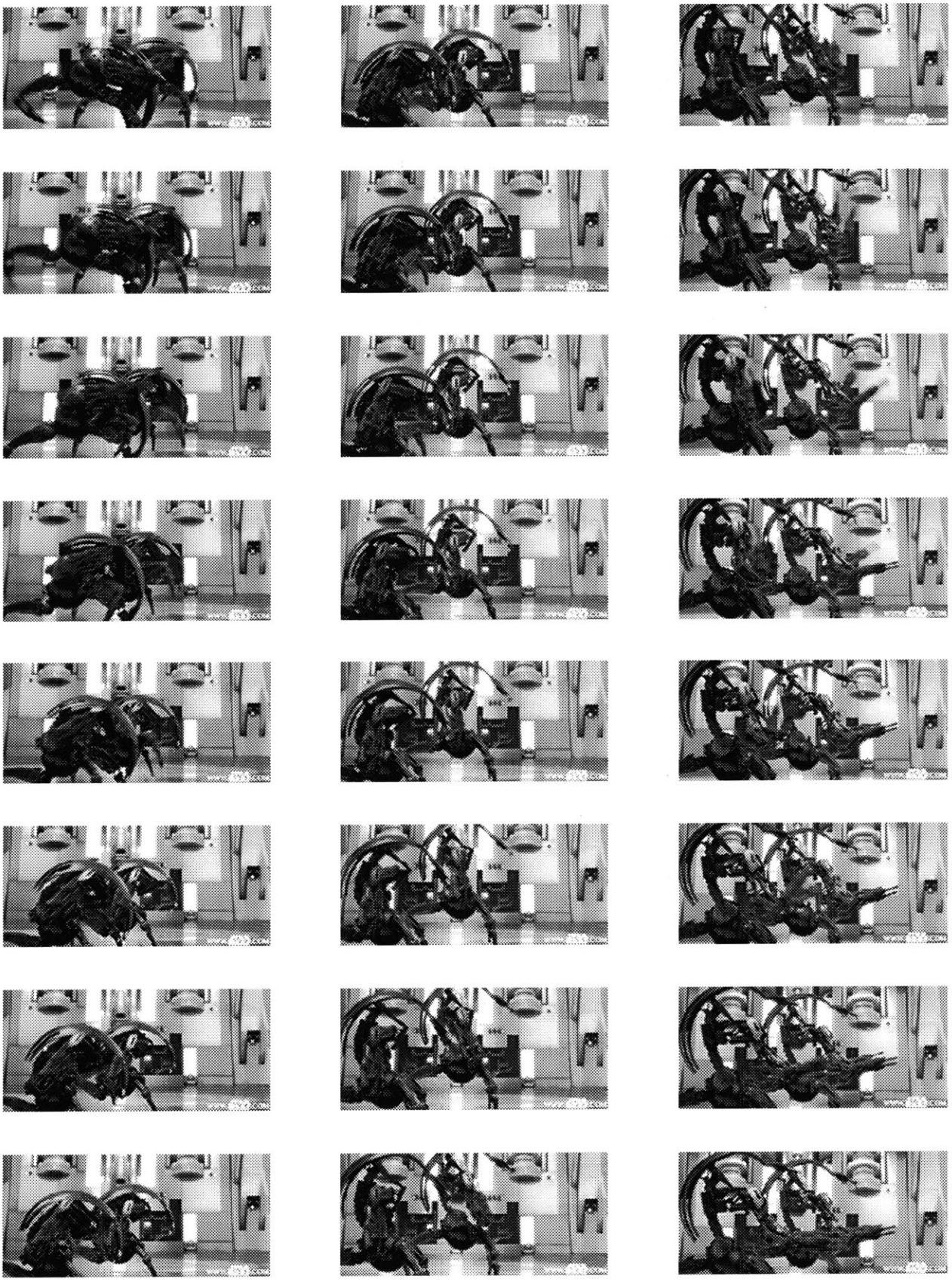


Figure 063:
Star Wars: Episode I
frame sequence

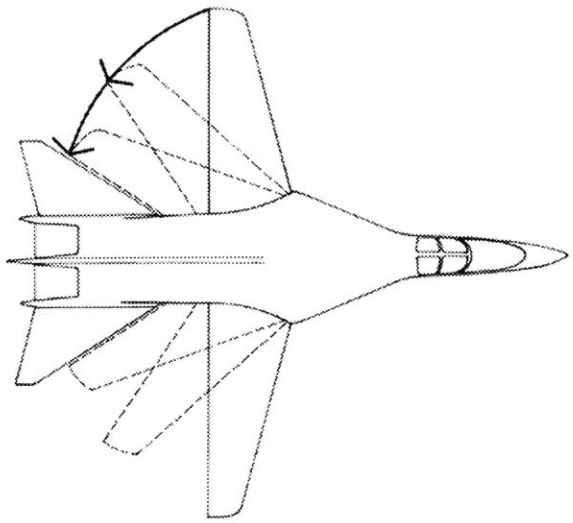
Wars: Episode I', it is evident that stability is a primary concern throughout the transformation process. These warriors engage their legs into a triangulated position while the rest of their body opens up. As the weight of their body shifts, a continuous adjustment to carry these asymmetrical loads persists. Stability is constantly maintained without conceding vulnerability.

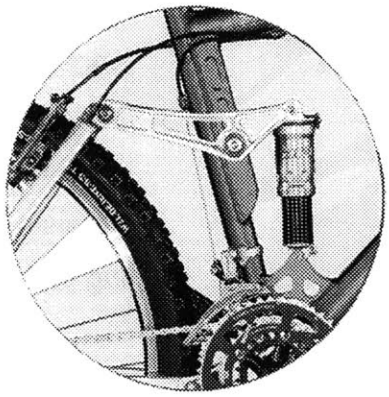
As changes in geometry take place in Proposal 002, the load forces on the skin continue to be transferred to the frame. The structural change of the surface in the expanded condition increases the depth of the opening. This depth change allows lateral forces (wind loads) to be transferred more efficiently to the frame from the skin. Also, positive pressure that is present in the flat collapsed stage breaks up as the surfaces become out of plane with each other. The creation of negative and positive wind pressure is present in the expanded condition.

PERFORMANCE

The characteristics of the boundary are integrally dependent on its form. Permeability of light and air are dependent on the configuration of the system. The potential of this relationship is that the fine tuning of the boundary brings about a greater awareness of external conditions and efficiencies in performance.

The F-111 airplane conducts a transformation dependent upon speed of travel. The wings are able to pivot to decrease the wing span. This act allows the plane to move at greater speeds with a greater amount of efficiency. Wind pressure affecting the aircraft is altered due to the opera-





tional form and speed of the airplane.

Figure 064:
F-111 Airplane

Figure 065:
Truth ICT

Varying conditions are also dealt with in the application of the multiple-pivot rear of the Truth ICT bike. The design of this pivoting component has been brought about by the need to traverse an uneven landscape. Through the use of an articulated steel member, the shock is able to brace the impact and load of the rear wheel.

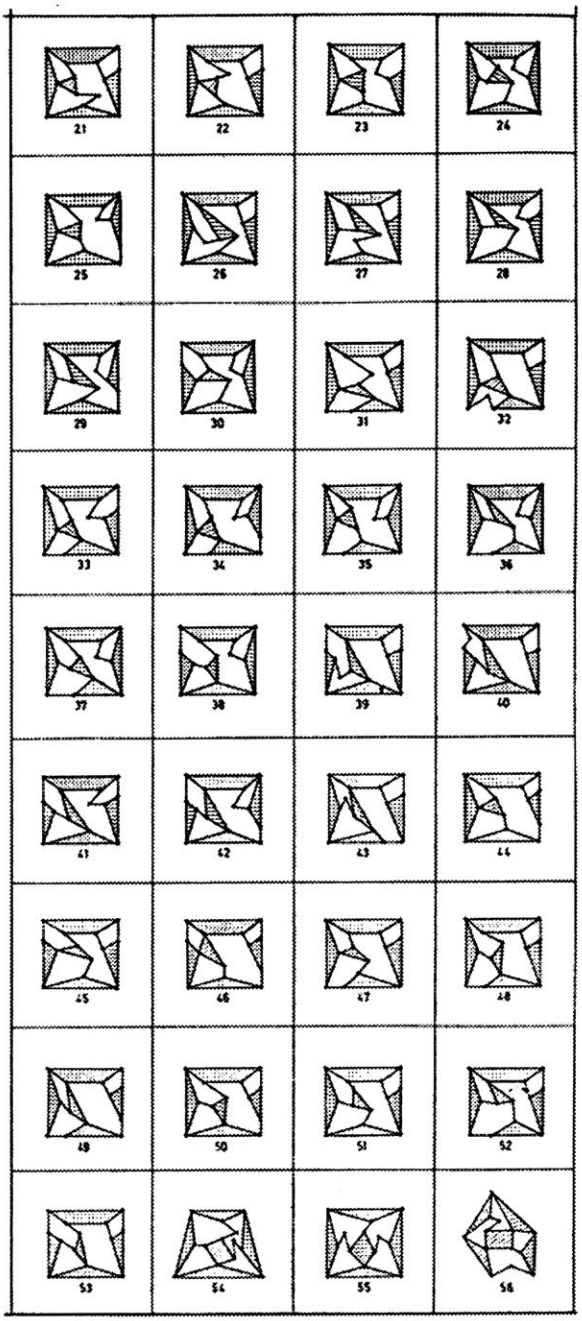
The design of an adaptable system through geometric change creates the basis for a transformable architecture. The performance of this system is not only measured in terms of quantitative values, but also in terms of the spatial quality achieved.

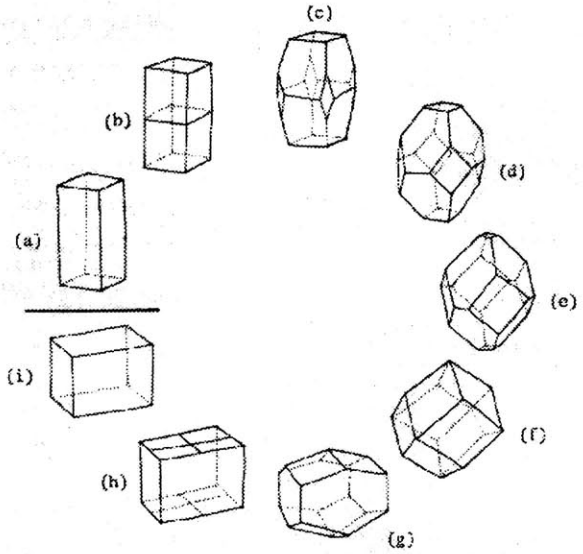
The thematising of the building envelope is not merely a question of aesthetics. Within certain architectural concepts, the skin can gain new spatial, structural and climactic functions. The facade as membrane becomes a climate modulator which regulates the flow of energy between internal and external environments.[9]

-Philip Oswalt

Repeating

4


21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)

CHAOS

The notion of geometric manipulation and system variation is evident in Proposal 002. The proposition is designed to be parametrically manipulated and modified to tailor itself to the needs of the site, structure and program. Similar to the exploration by engineers into kinematic chains, the proposal aims to define variation that is possible. The mechanism that governs the manipulation of kinematic chains is through a mathematical formula that resolves the finite number of variations possible. An initial obsession into geometric manipulations is shown on the following pages. A series of five transformations have been applied to the initial state of the object. The object is then redrawn and articulated at each stage.

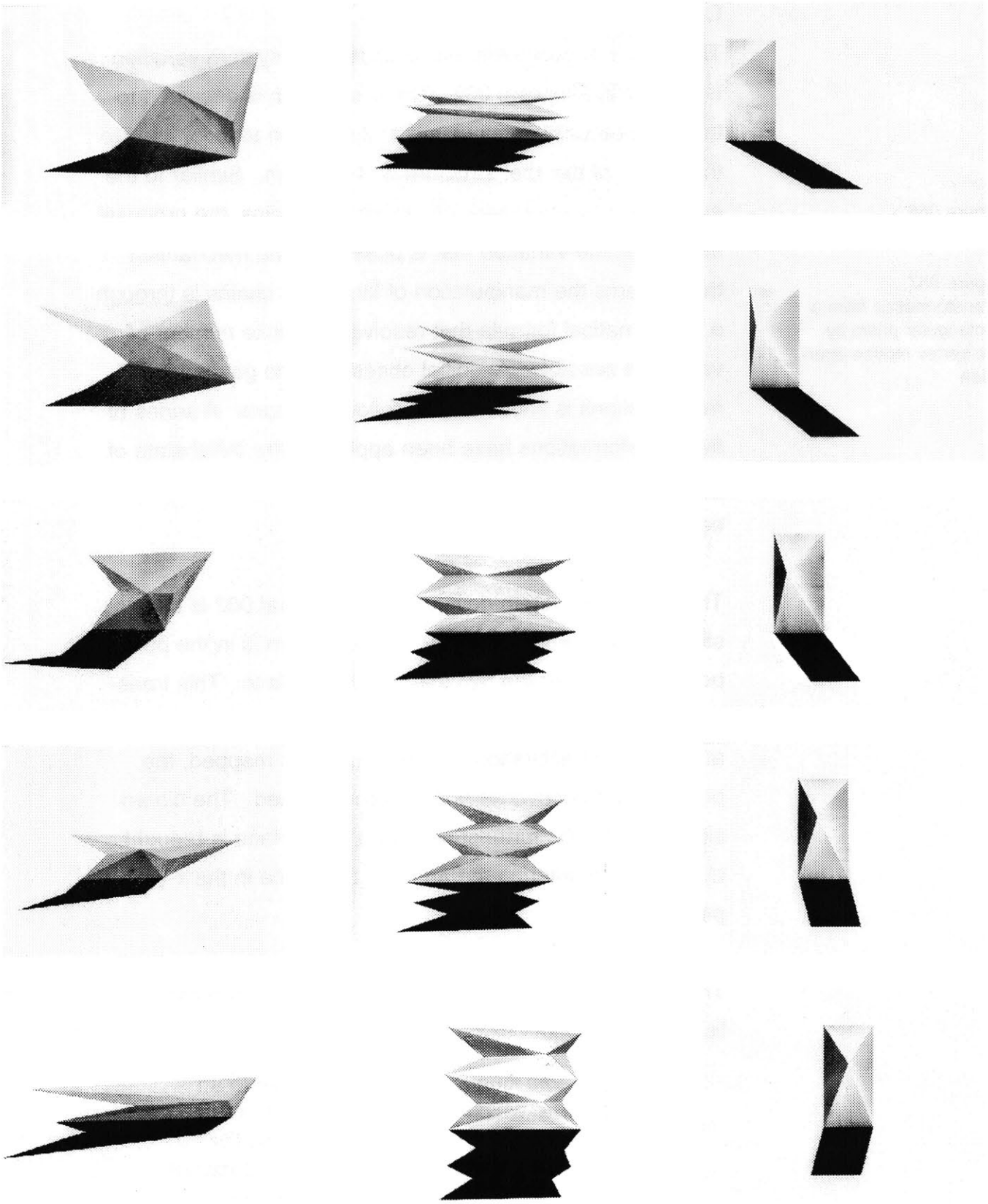
Figure 066:
Kinematic Chains

Figure 067:
Transformation from a rectangular prism by the vertex motion operation

The envelope system developed in Proposal 002 is constrained by a similar strategy. The activation is in the perpendicular axis of the two dimensional surface. This translation results in the furthest point on the z axis to be located at the point of activation. As the surface is mapped, the points start to converge and become pinched. The dimension between the furthest points on the surface is brought closer without altering the angle of the frame in the x-y plane.

The creation of a geometry that morphs has been established. As William Zuk comments:

> "Deformable kinetic architecture refers to an architecture which has the potential to allow for change which fundamentally affects the whole form....A further general characteristic of this architecture is that all the parts of the basic deformable form are contiguous and remain so throughout any transformation that might take place."[10]



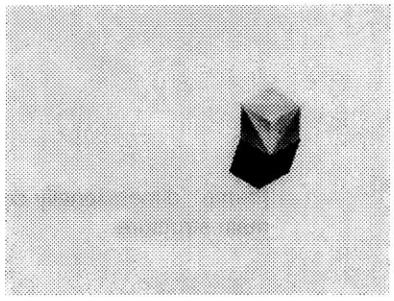
Geometric Manipulation
using Berol Draughting
314 pencil

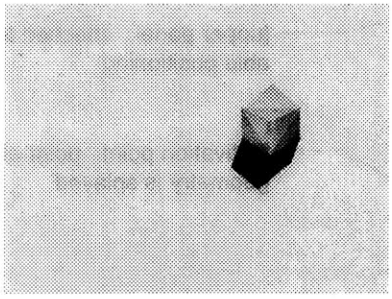
Figure 068:
Series 1

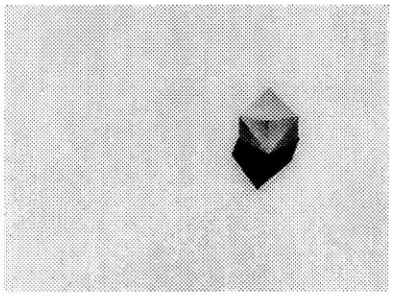
Figure 069:
Series 2

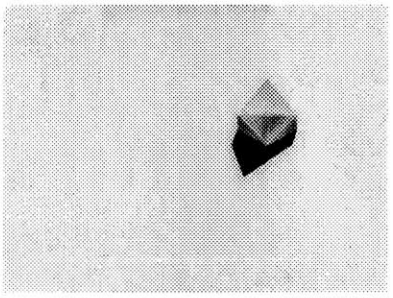
Figure 070:
Series 3

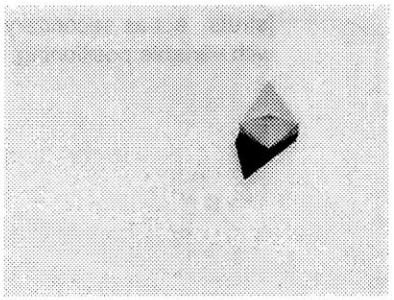
Figure 071:
Series 4











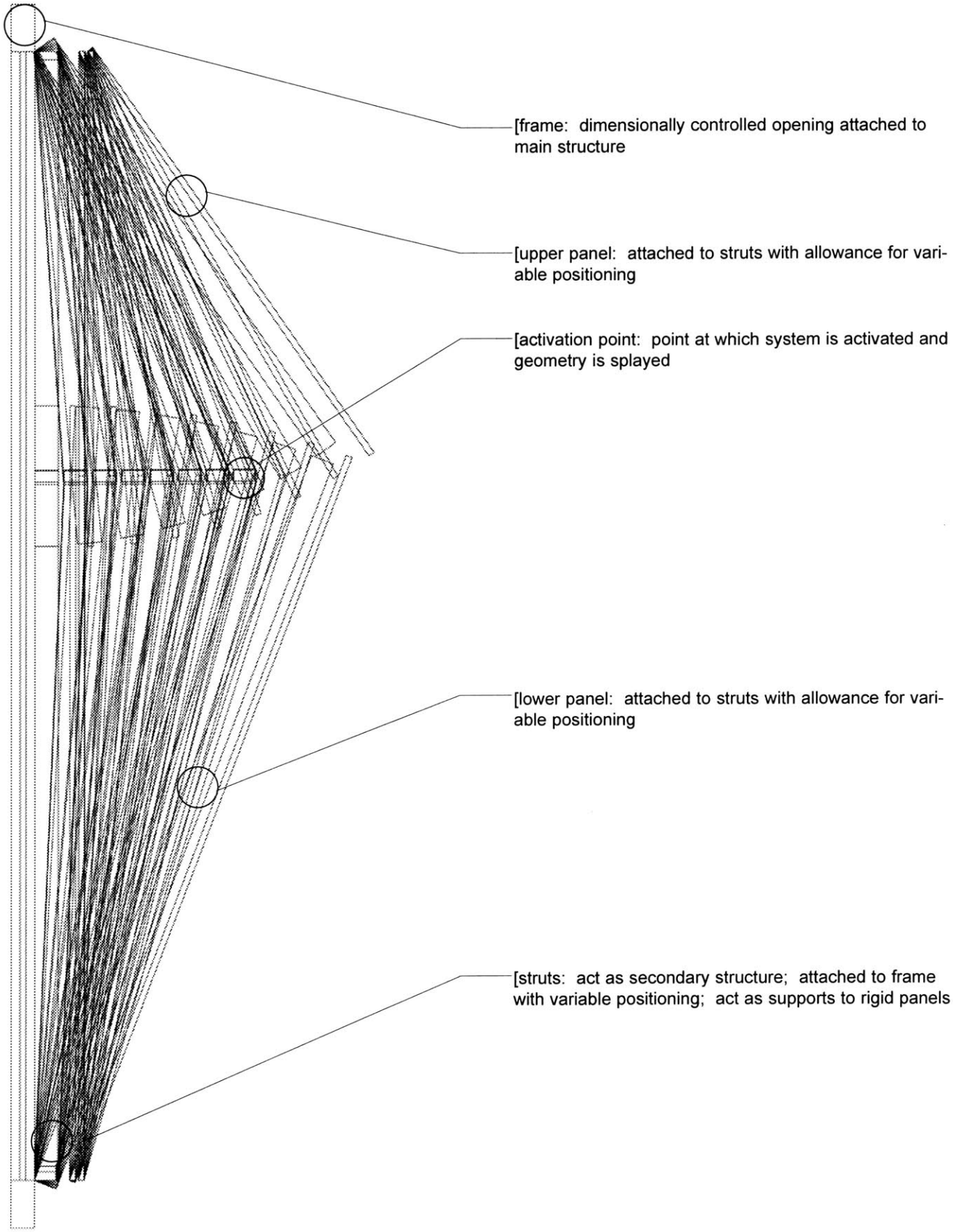

[frame: dimensionally controlled opening attached to main structure
[upper panel: attached to struts with allowance for variable positioning
[activation point: point at which system is activated and geometry is splayed
[lower panel: attached to struts with allowance for variable positioning
[struts: act as secondary structure; attached to frame with variable positioning; act as supports to rigid panels

Figure 072:
Proposal 002 - Section

This proposition unveils the relationship of the force applied to a form and the action that results through movement.

MATERIAL

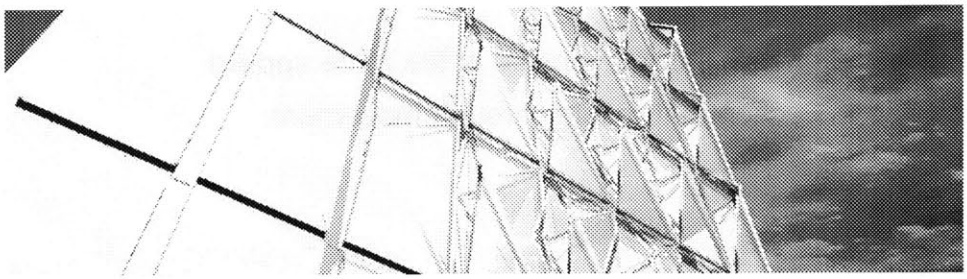
The potential of the system's response is both active and passive. The external, active layer is mechanically driven, while the internal passive layer is materially driven. The meaning of this distinction is to differentiate the manner in which each layer of the system is activated.

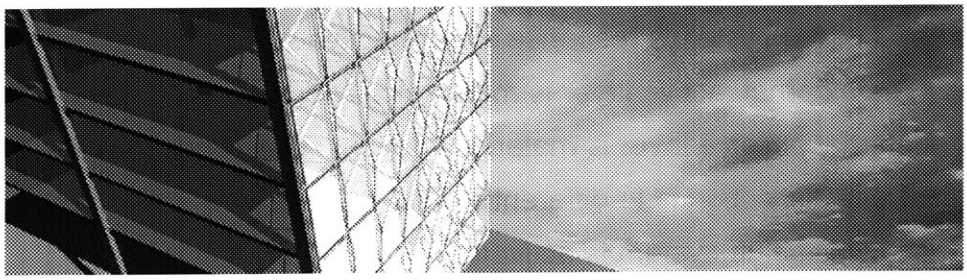
The glass on the external surface is attached to the aluminum struts of the system. As the module moves, the glass surfaces slip by each other. The attachment apparatus allows for various material panels to be attached, from glass to metal to ETFE panels.

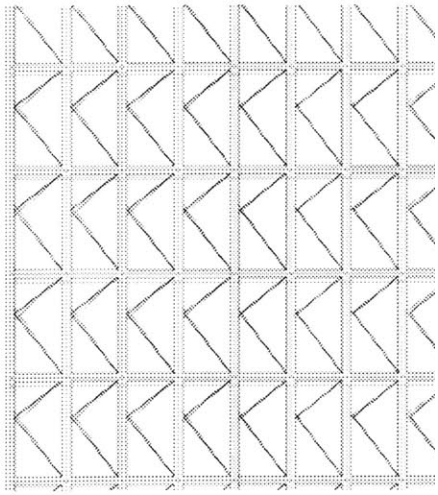
The glass on the internal surface is envisioned to be attached to a series of spring joints. The joints are made of a shape memory polymer such as nitinol. The expansion of this interior layer is controlled through temperature activation of the material. As the interstitial space heats up, the joints expand to create gaps in the inner layer. This planar change is brought about through the material responding to an external energy source. Currently, the proposal does not employ nitinol since large quantities of it would be required to shift the inner skin, but the potential of this behavior is acknowledged.

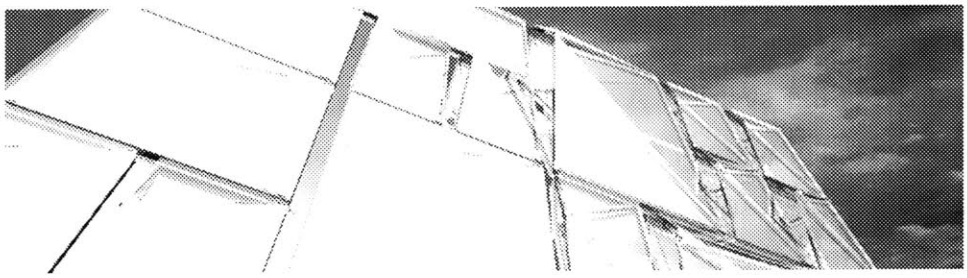
SCALE

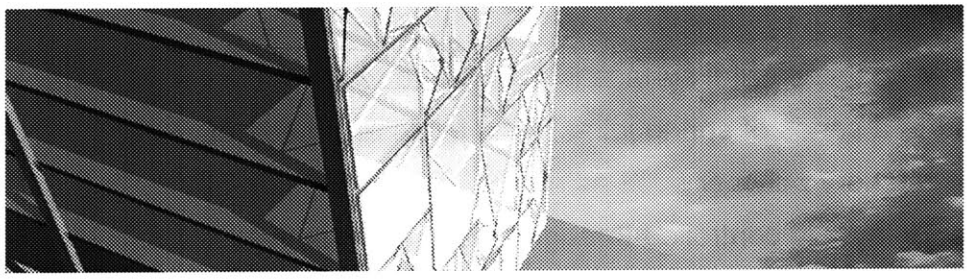
The repetition and manipulation of the module allows for

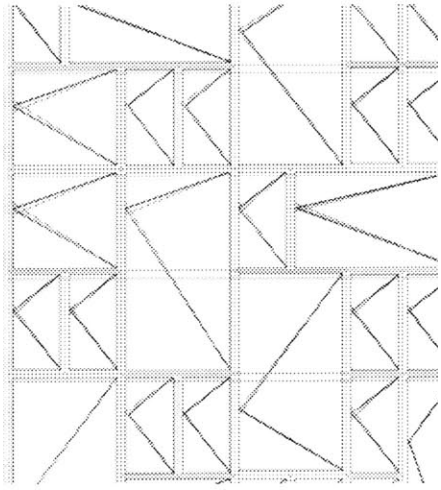


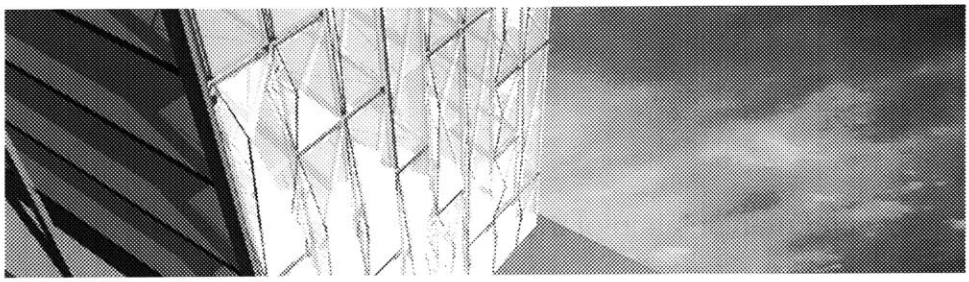


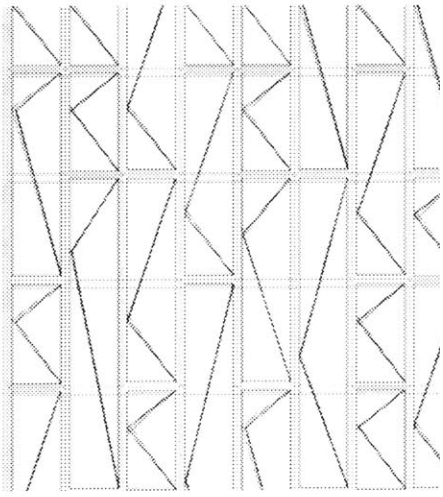












insight to be gained into the architectural scale. The section of a hypothetical building is constructed to provide the framework for facade variations to be developed.

Figure 073:
Variation 001

Variation 001 describes a standard cellular approach that requires multiple components of the same size to be produced. The system is designed vertically to accommodate a floor to ceiling space. The operation of the facade can be in unison or individual. The form that the facade takes is captured through the activation and depth of the system.

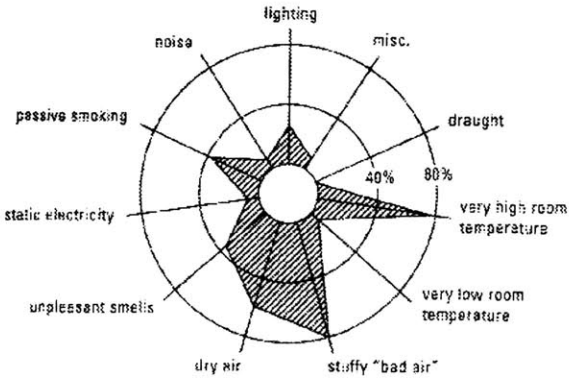
Variation 002 moves towards the possibility of a larger framework governing the points of interaction. The structure behind becomes secondary as the scale of the elements take on their own proportions. The space behind the module is allowed to span one or two floors. The horizontal dimension can vary as well with relation to the endeavor behind the facade.

Figure 074:
Variation 002

Variation 003 locks the dimensional variation in the vertical orientation. The span is articulated as varying between two or three floors. This system along with the first variation create a vertical truss condition. As the members within the frame are activated, depth in the truss is created, allowing the system to create efficiencies as a whole as well as individual units.

Figure 075:
Variation 003

The compilation of these variations suggests endless possibilities and combinations. The origin of each variation is the base module. With this prototype as the starting point, the system can be further developed and its boundaries stretched.


lighting
misc.
draught
40%
80%
very high room temperature
very low room temperature
stuffy "bad air"
dry air
unpleasant smells
static electricity
passive smoking
noise

APPLICATION

Figure 076:
Most Frequent internal environmental complaints

As buildings are moving towards energy efficient propositions, the variable volume concept proposes a potential direction. Reducing the consumption of energy used by mechanical systems has long-term benefits from an increased initial investment. The proposal has been developed with the idea that as spaces respond to climactic conditions, the burden of internal systems will be reduced. Even more interesting is the observation that the boundary that creates the space is full of potential through the use of variation.

The value in re-engineering a space within a given framework is two fold. First, the infrastructure for change is built into the construction of the space. James Glieck explains this notion in a direct way:

> "New Hopes, new styles, and most important, a new way of seeing. Revolutions do not come piecemeal. One account of nature replaces another. Old problems are seen in a new light and other problems are recognized for the first time. Something takes place that resembles a whole industry retooling for new production."[11]

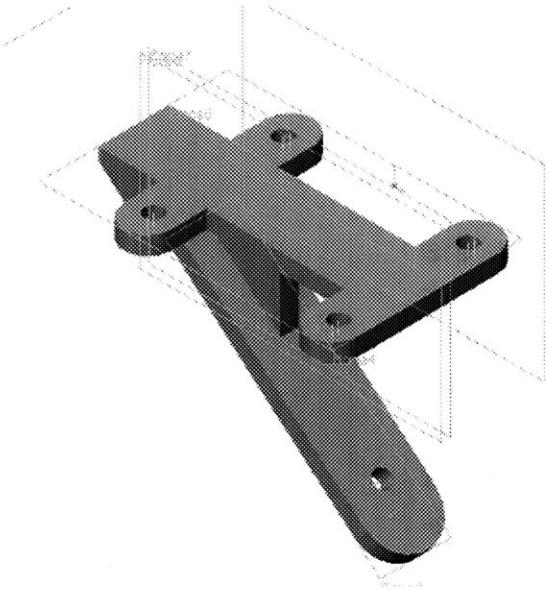
The realization of a new way of constructing and controlling the built effort is essential to producing new environments. Second, the creation of a dynamic volume lends to the need to reexamine the occupation of space. The manner in which enclosure is defined leads to the clarity in the human interface of buildings.

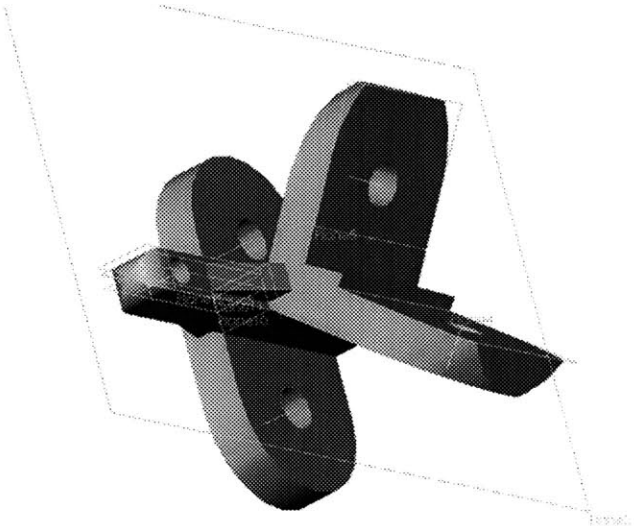
What constitutes the architectural world system? It could be asked, when related to the biological model, if architecture must now always be an open and dynamic system, rejecting completely the near equilibrium of the static or closed system? After all, if architecture has undergone radically positive conceptual transformations via the biological model of systems, will it ever, as a discipline, be able to refer to equilibrium or the fixed again? It will not, even if buildings appear otherwise.[12]

-Neil Denari

Composing

5





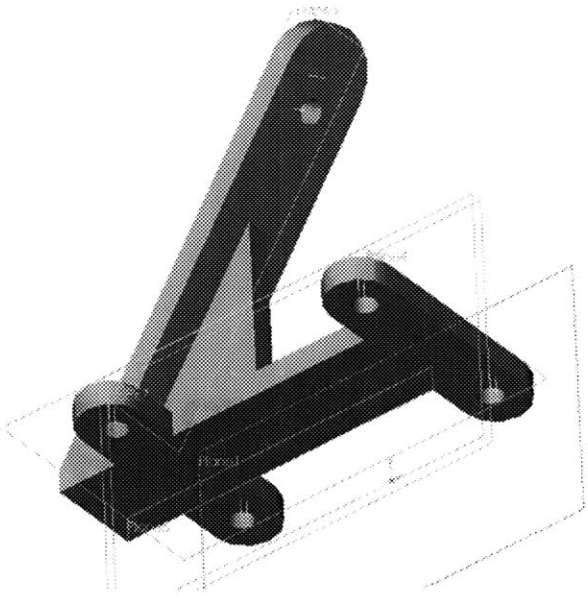


Figure 077:
Component 1 - connection at top of frame

Figure 078:
Component 2 - providing connections to all four struts

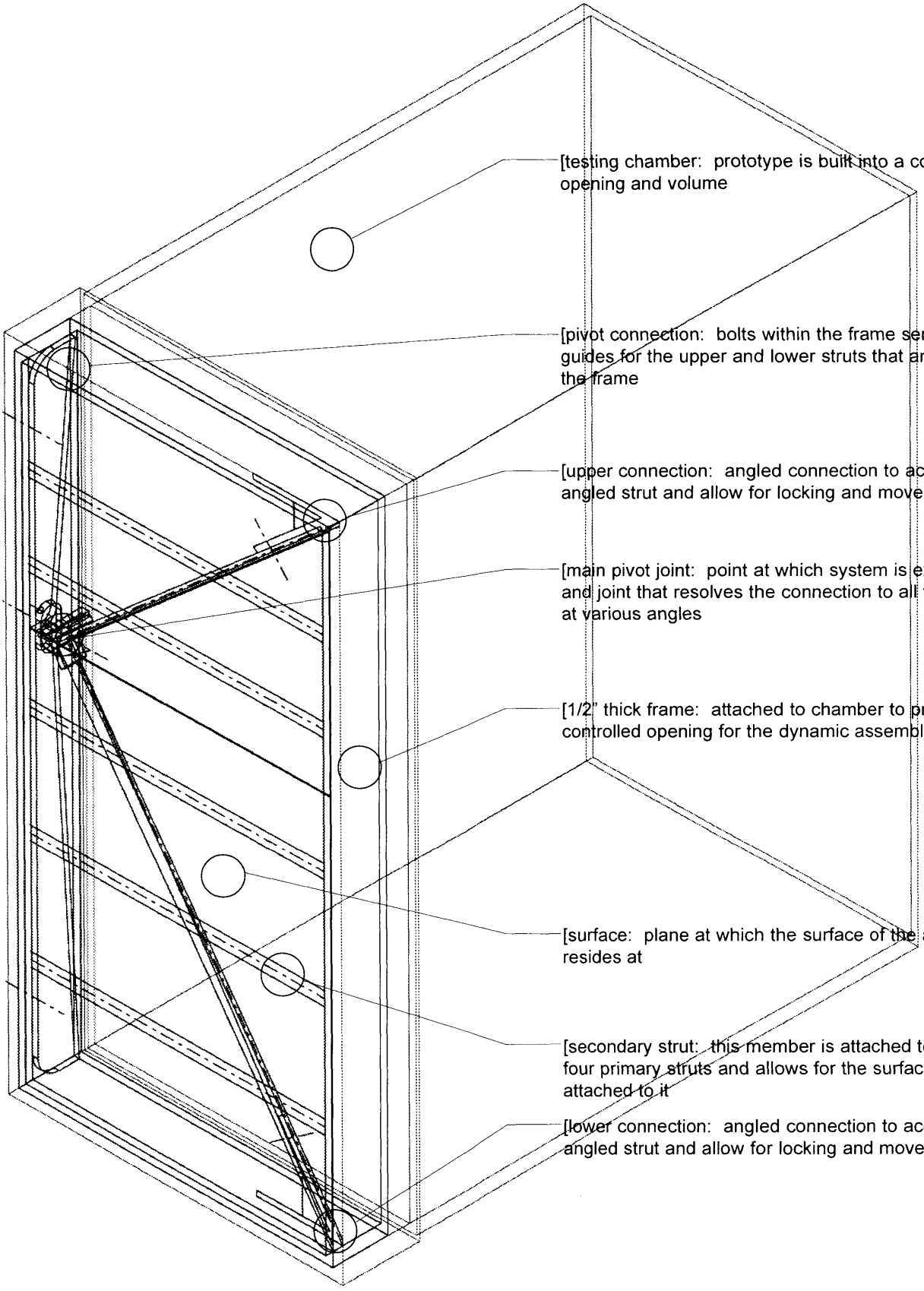
Figure 079:
Component 3 - connection at bottom of frame

COMPONENT

The development and production of a working model is initially investigated at a smaller scale. As the movement is tested and refined, the making of full scale physical Prototype 001 is initiated. The specialized joints for the prototype are produced using a three-dimensional software program. This process allows the pieces to be physically created through the three-dimensional plotter. The components designed in this manner have specialized angles that deal with the operation of the module. These components could eventually be cast in metal, but for the purposes of the working prototype remain in plastic.

The design of the pieces within the digital environment is critical. The minimum tolerance level ensures that the pieces will interact in a precise way. The movement of the assembly depends on a high level of accuracy. The other advantage of designing the pieces in this way is that the movement can be tested within the digital environment before physical production. The software allows for an assembly model to be created with the degree of movement that each piece would undertake. With this operation performed, the components can go through a design refinement process before final production.

The cost involved in making unique components is viable due to the efficiencies of the manufacturing process. The argument for using off the shelf components is not substantiated. Low production runs can be allowed for through the digital design and manufacturing processes. The ability to vary these components parametrically allows for great latitude in geometric and scale variations.


[testing chamber: prototype is built into a controlled opening and volume
[pivot connection: bolts within the frame serve as guides for the upper and lower struts that are parallel to the frame
[upper connection: angled connection to accommodate angled strut and allow for locking and movement
[main pivot joint: point at which system is expanded and joint that resolves the connection to all four struts at various angles
[1/2" thick frame: attached to chamber to provide a controlled opening for the dynamic assembly
[surface: plane at which the surface of the assembly resides at
[secondary strut: this member is attached to one of the four primary struts and allows for the surface to be attached to it
[lower connection: angled connection to accommodate angled strut and allow for locking and movement

MODULE

Figure 080:
Axon of Module

The module is assembled on the roof of MIT within the Building Technology testing chamber. The frame of the prototype is made out of 1/2" thick aluminum. The frame is a dimensionally controlled opening that provides narrow tolerances for the assembly. The struts are made of 3/8" thick aluminum. The struts have been designed to lock into the frame when the assembly is in the flat state. The radiused edges on the struts allow for pivoting in a single direction. The making of these components has been controlled through the use of a computer controlled water jet cutter.

The supports that are attached to the struts are 1" angles with 1/8" walls made of aluminum. These members have been cut to the angle at which the struts are placed at. The joint that connects these members to the struts have been three-dimensionally plotted when the angle deviates from ninety degrees. These components as well would be cast in metal.

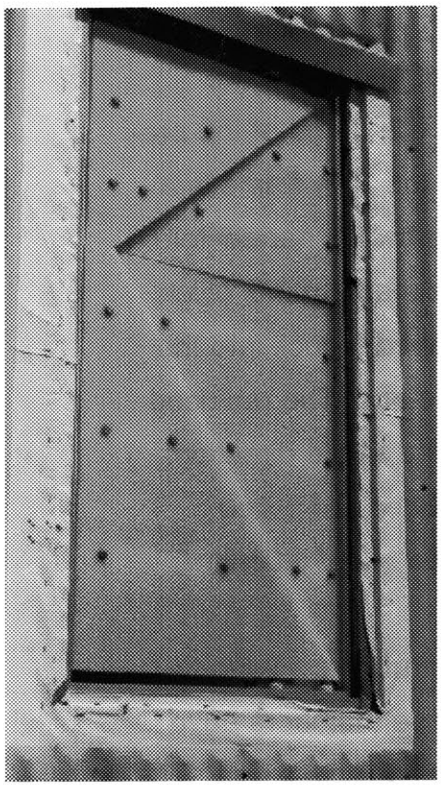
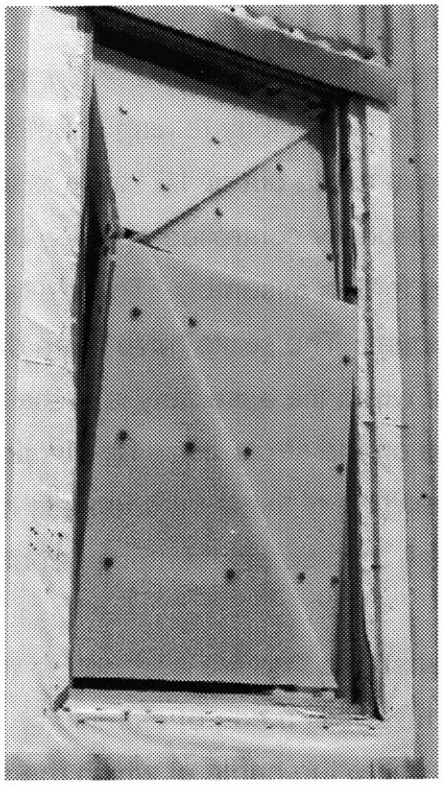
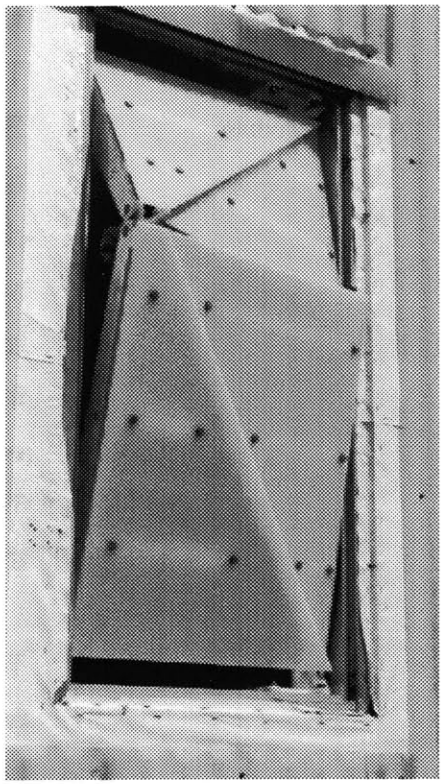
The module demonstrates the physical reality of the digital model. Precision that is achieved in the digital median has been carried over to the physical reality of construction. The trajectory of this methodology is best summed up by William Zuck's concept that:

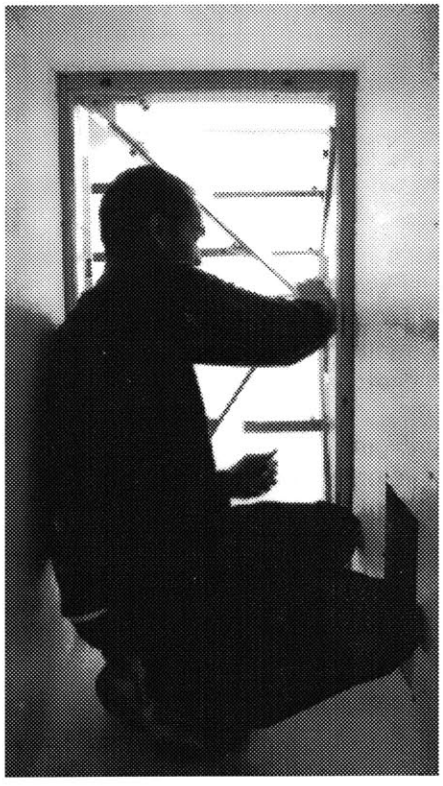
> "Handcrafted Buildings would be obsolete in terms of kinetic structures. The reason is that the materials used would be of such a nature that their strength, shape, and precision tolerances would require fabrication under controlled industrial conditions, possibly with large machines. Additionally, should the structures be produced for a broad market, the need for industrialization is clear."[13]

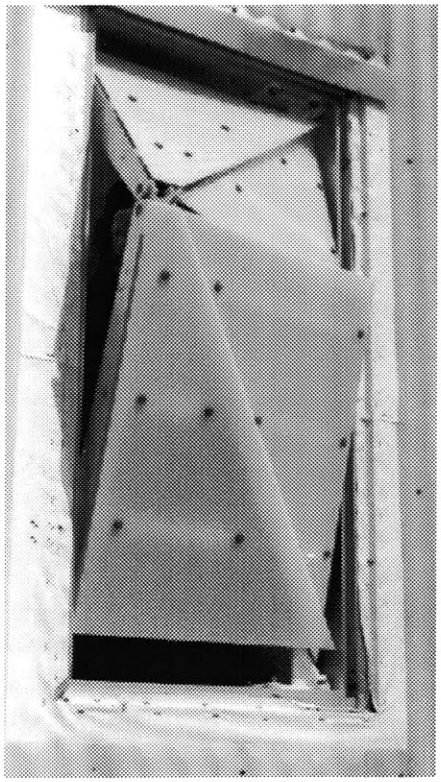
Figure 081:
External Sequence of Module expanding
(next page)

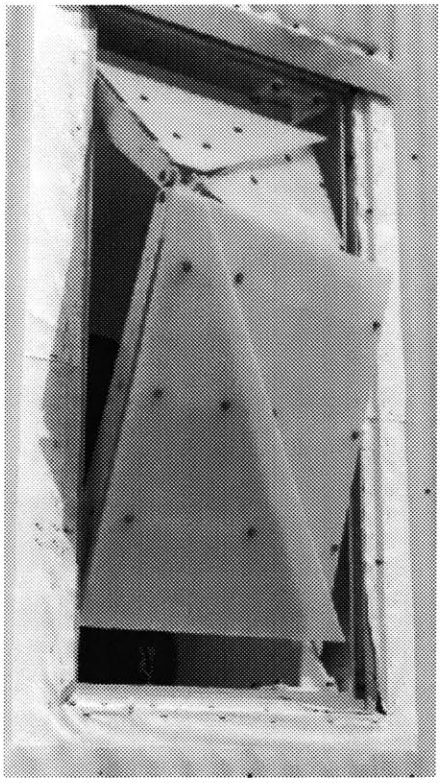
Figure 082:
Internal Sequence of Module expanding
(next page)

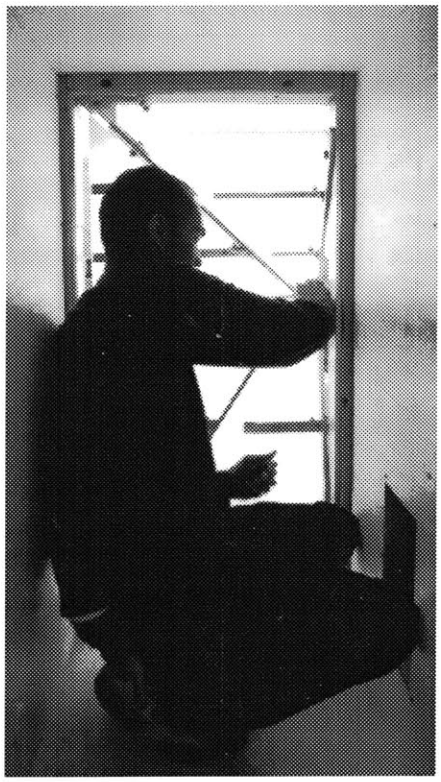
Figure 083:
Details of Module after expansion
(next page)

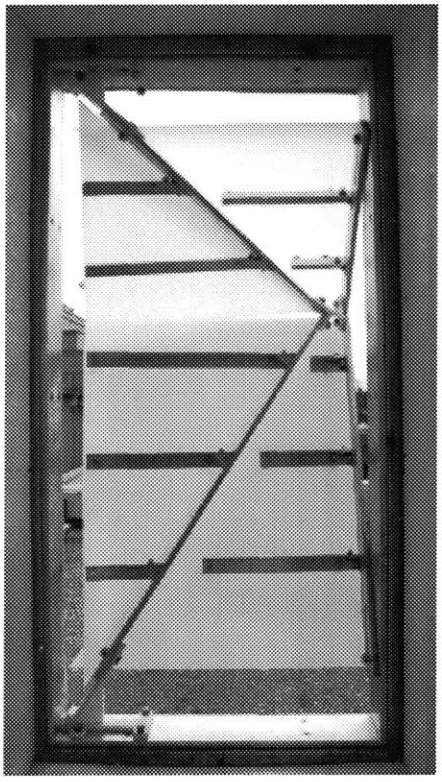




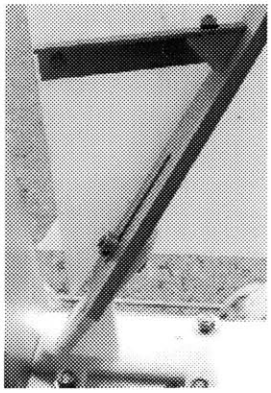













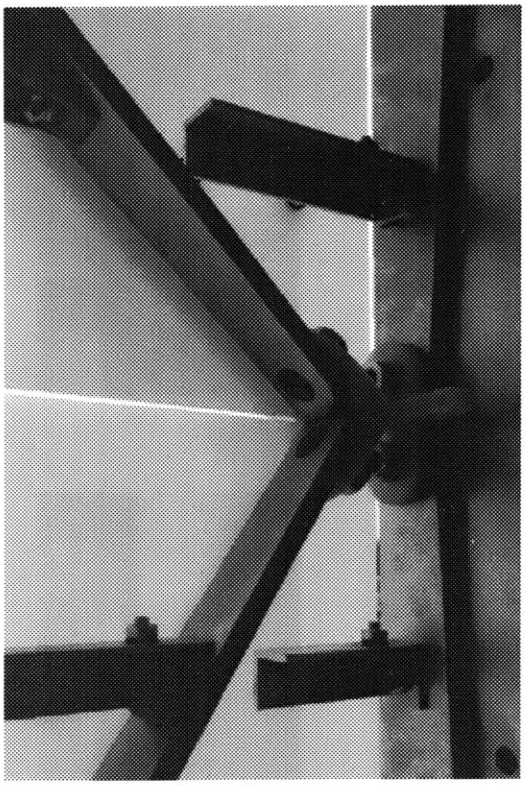


Figure 084:
Detail at main hinge connection - system closed

Figure 085:
Detail at main hinge connection - system expanded

The operation of the module and the components that make up it work with the precision designed and imagined in the digital realm.

SYSTEM

The making of the prototype has lead to an idea of how a larger scale system can be created. Architecture and movement become integrated. Similar to the development of the elevator, the variable volume device brings about a shift in the making of inhabitable environments. The elevator allows for buildings to become taller enterprises because of their capability of fast vertical transport. This development intensified occupation thus changing the social ramifications of the spaces developed. Also, the making of the urban landscape has permanently been altered.

The variable volume device through the implications of this research agenda is another incident in a shift in building technology. The device begins to indicate a very different relationship that can exist between the interior and exterior. In creating a dynamic boundary condition, the prototype demonstrates the potential of responsive and flexible volumes.

With the advent of reconfigurable spatial constructs, the ideas of occupation becomes enhanced. The argument can be posed in two ways. The first reaction to volumes that constantly are in flux could be disconcerting. The idea of coming back to a space that is never the same can lose the permanence of memory and comfort of understanding the space the way that one left it. The other side of the proposition delivers the joy of discovery. The sense that the

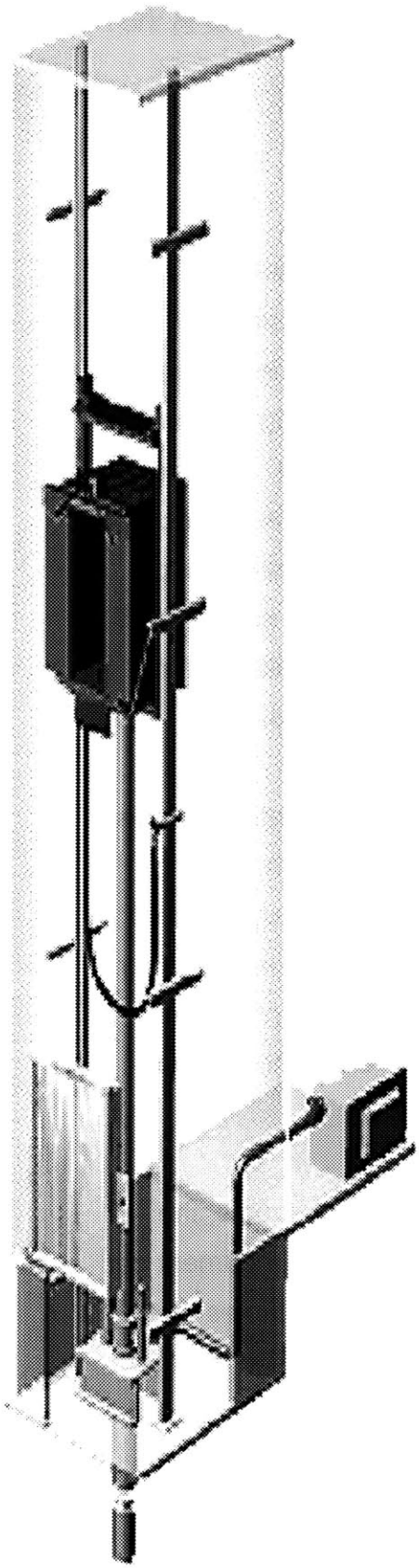


Figure 086:
Elevator Axonimetric

change is constant and brings about moments of clarity with the sense of transformations. The latter argument is the direction that the research operates on.

LANDSCAPE

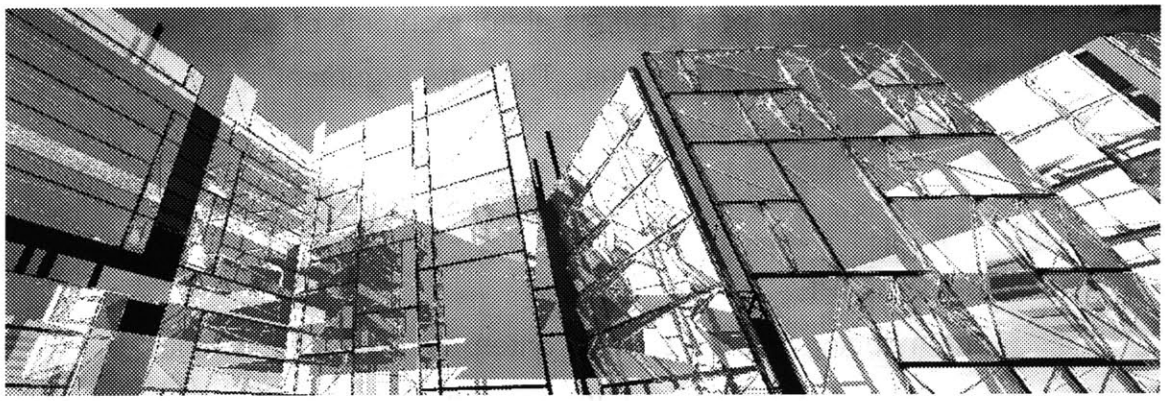
The mapping of a larger scale enterprise begins to indicate texture and composition of the expanded system. The instigation:

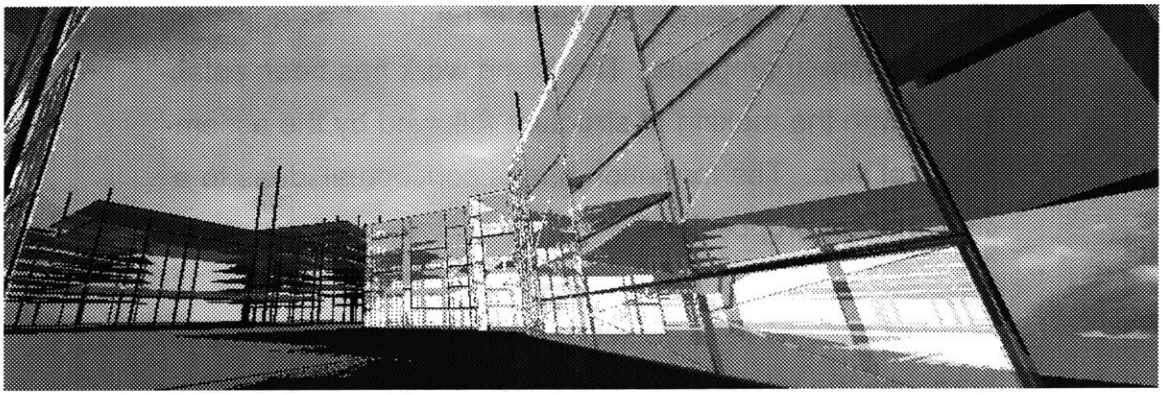
> "when an architectural idea is to be realized, the force with which that idea communicates itself through that building becomes an important issue. Thus given a pertinent response, its realization deserves the care and discipline, irrespective of the formal efficacy of the architectural language, though, of course, requiring the latter."[14]

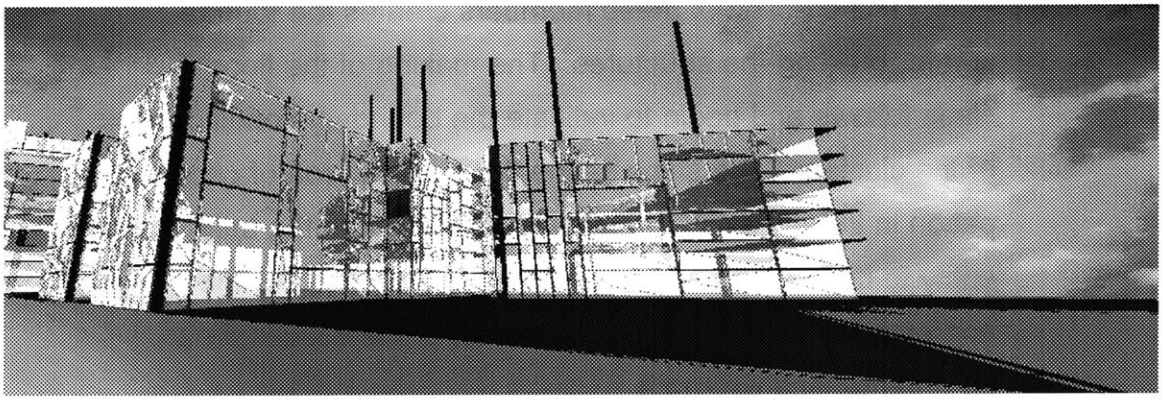
One the following pages, a scene is rendered as a field of construction in progress. The frame work has been established with the making of structure followed by the assemblage of skin. The formation brings conceptual ideas to a hypothetical proposition.

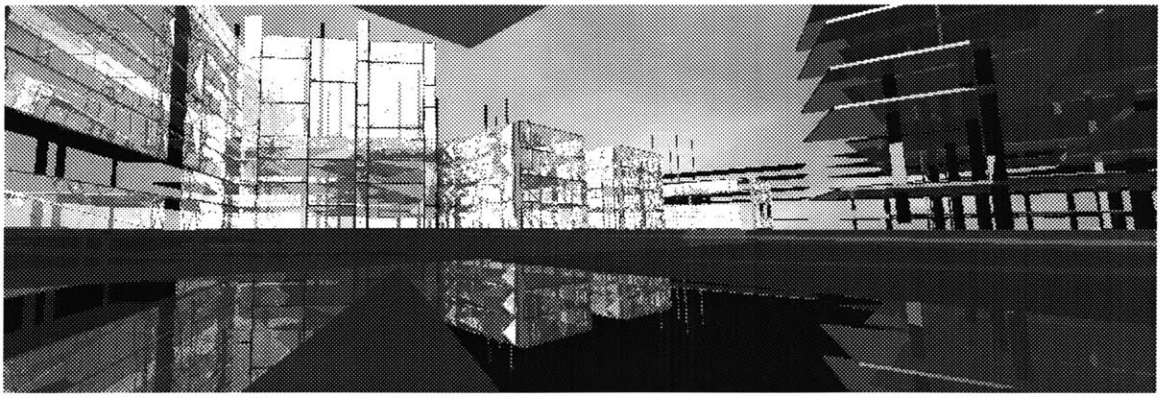
Figure 087:
Series of views of an imagined architectural landscape
(next page)

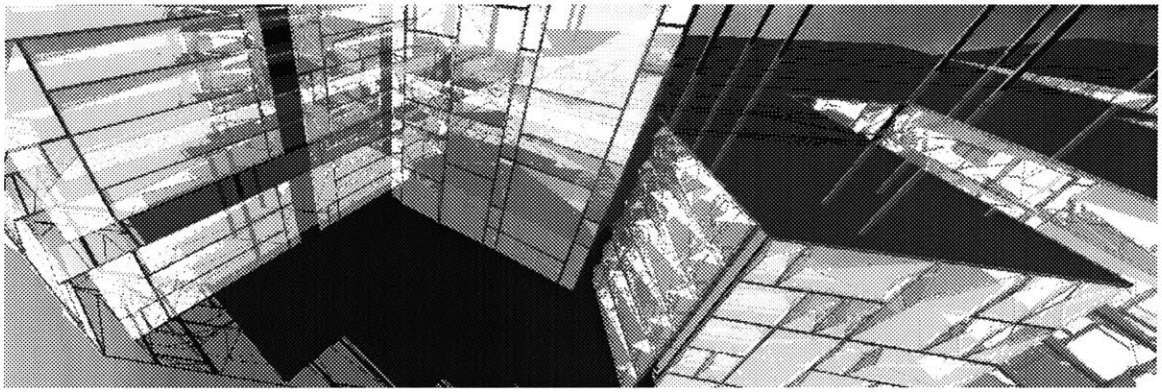
A set of rules have been set up and then operated upon to compose the landscape. The initial building block is the column. The erection of these members creates the foundation for building the structures. The making of the floor slabs follows and begin to indicate the boundary conditions of the clusters. The slabs define the surface area of occupation in the x-y axis. The skin is added last to the built entity to define the enclosure zone. The zone is flexible and manages the volumetric construct of the spaces created (internal and external).



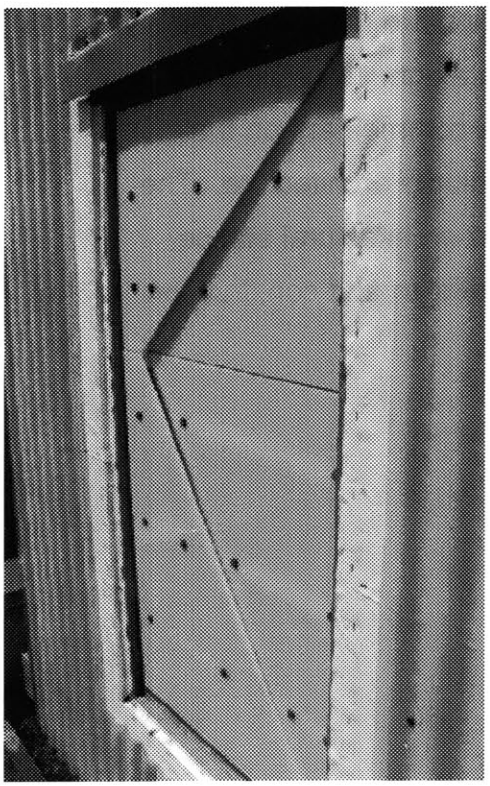


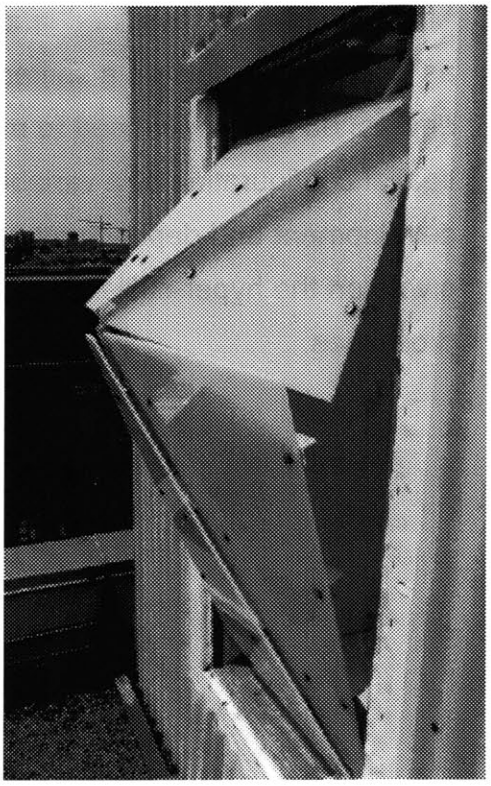






The images of an imagined landscape are rendered to act as the catalyst towards a shifted paradigm. Moments are envisioned and sequenced to make commentary on the spatial configuration of a variable volume architecture. The development and deployment of this architectural stance pivots on the hyper-collision of the design and construction processes.





conclusion | forward

> "We are heading toward a kinetic, time-spatial existence; toward an awareness of the forces plus their relationships which define all life and of which we had no previous knowledge and for which we have as yet no exact terminology. The affirmation of all these space-time forces involves a reorientation of all our faculties."[15]
>
> -L. Moholy-Nagy

Figure 088:
Prototype - initial stage

Figure 089:
Prototype - expanded stage

The proposals articulated in this document establish a research towards a discovery of methodology and the basis for a theoretical platform. The projects are viewed as experimental propositions in which various hypotheses have been identified and investigated. The establishment of an architectural direction has been critical in formulating a platform for a dynamic spatial and social structure.

The making of the prototype brought about revelations on several fronts. The geometry that is settled upon came about by thinking of stability through triangulation. The asymmetrical nature of the geometry is a direct consequence of the expansion process. Since the rigid panels that are attached to the struts are displaced in different planes, the panels would collide with each other if the geometry was symmetrical. The activation of the assembly also revealed that once the seal of the system is broken, the continued expansion will lead to a greater gap. At the point of maximum expansion, the prototype displayed a need for a locking mechanism to transfer the loads carried

by the struts to the frame. These issues have lead to a developed foundation on which further refinement can be initiated.

The discussion towards spatial constructs identified in the work presented cannot exist without the consideration of flexibility. At each level of architectural investigation, acknowledgement and discussion must be given to the material, volumetric and structural frameworks. Within this territory lies the untapped resources towards an enriched occupation of space.

Volumes fluctuate.
Boundaries dissolve.
Architecture lives.

FIGURE CREDITS

001: author
002: TIME Magazine. April 2001.
003: author
004: author
005: author
007: author
008: author
009: author
010: author
011: author
012: author
013: Schaeffer, Oliver.
014: Schaeffer, Oliver.
016: author
017: author
018: author
019: author
020: author
021: author
022: author
023: author
024: author
025: author
026: author
027: author
028: author
029: author
030: author
031: author
032: author
033: author
034: author
035: author
036: author
037: author
038: author
039: author
040: author
041: author
042: author
043: author
044: author
045: author
046: author

047: author
048: author
049: author
050: author
051: author
052: author
053: author
054: Denari, Neil M.
055: Denari, Neil M.
056: Bernd and Hilla Becher.
057: author
058: author
059: Wigginton, Michael.
060: Kronenburg, Robert.
061: Wigginton, Michael.
062: author
063: Star Wars: Episode I movie trailer.
064: Zuk, William.
065: Wired Magazine. April 2001.
066: Jensen, Preben W.
067: Williams, Robert.
068: author
069: author
070: author
071: author
072: author
073: author
074: author
075: author
076: Yeang, Ken.
077: author
078: author
079: author
080: author
081: Razvi, Amina.
082: Razvi, Amina.
083: author
084: author
085: author
086: author
087: author
088: author
089: author

NOTES

1 Churchill, Winston. 28 October 1943. Speech to the House of Commons.

2 Salter, Peter. 'Bespoke Territory.' Page 200.

3 Wagner, Otto. MODERN ARCHITECTURE. Page 94.

4 Williams, Robert. NATURAL STRUCTURE. Page 20.

5 Salter, Peter. TS: INTUITION & PROCESS. Page 26.

6 Masonry Council of Canada. Guide to Energy Efficiency in Masonry and Concrete Buildings. Page 6.

7 Salter, Peter. TS: INTUITION & PROCESS. Page 26.

8 Gleick, James. CHAOS: Making a New Science. Page 46.

9 Oswalt, Phillip. "Grutuch/Ernst." 'ARCHITECTURAL DESIGN PROFILE No 122 - Architecture on the Horizon.' Page 32.

10 Zuk, William. KINETIC ARCHITECTURE. Page 98.

11 Gleick, James. CHAOS: Making a New Science. Page 39.

12 Denari, Neil M. Gyroscopic Horizons. Page 18.

13 Zuk, William. KINETIC ARCHITECTURE. Page 146.

14 Burdett, Richard. 9H No. 8 1989 ON RIGOUR. Page 5.

15 Moholy-Nagy, L. vision in motion. Page 268.

BIBLIOGRAPHY

Attali, Jacques. NOISE - the political economy of music. Minneapolis: University of Minnesota Press, 1989.

Brookes, Alan J. and Grech, Chris. THE BUILDING ENVELOPE + CONNECTIONS. Oxford: Architectural Press, 1996.

Burdett, Richard. 9H No. 8 1989 ON RIGOUR. London: 9H, 1989.

Chironis, Nicholas P. MECHANISMS & MECHANICAL DEVICES SOURCEBOOK. New York: McGraw-Hill, Inc., 1991.

Denari, Neil M. Gyroscopic Horizons. New York: Princeton Architectural Press, 1999.

Gleick, James. CHAOS: Making a New Science. New York: Penguin Books, 1987.

Hertel, Heinrich. Structure - Form - Movement. New York: Reinhold Publishing Corporation, 1963.

Jensen, Preben W. CLASSICAL AND MODERN MECHANISMS FOR ENGINEERS AND INVENTORS. New York: Marcel Dekker, Inc., 1991.

Kronenburg, Robert. HOUSES IN MOTION - The Genesis, HIstory and development of the Portable Building. London: Academy Editions, 1995.

Masonry Council of Canada. Guide to Energy Efficiency in Masonry and Concrete Buildings. Ontario: 1982.

Mau, Bruce. "An Incomplete Manifesto for Growth." 'The International Design Magazine.' March / April 1999. New York: BeachHead of Delaware Inc., 1999.

Moholy-Nagy, L. vision in motion. Chicago: Hillison & Etten Company, 1947.

Oswalt, Phillip. "Grutuch/Ernst." 'ARCHITECTURAL DESIGN PROFILE No 122 - Architecture on the Horizon.' London: Academy Group Ltd., 1996.

Pescovitz, David. "Stuff Love - The new Competitive Edge." 'WIRED.' January 2001. New York: The Conde Nast Publications Inc., 2000.

Salter, Peter. 'Bespoke Territory.' Architectural Associations | THE IDEA OF THE CITY. Cambridge: MIT Press, 1996.

Salter, Peter. TS: INTUITION & PROCESS. London: The Architectural Association, 1989.

Wagner, Otto. MODERN ARCHITECTURE. Santa Monica: The Getty Center for the History of Art and the Humanities, 1988.

Williams, Robert. NATURAL STRUCTURE. Moorpark: Eudaemon Press, 1972.

Yeang, Ken. the skyscraper bioclimatically considered. West Sussex: Academy Editions, 1996.

Zuk, William. CONCEPTS OF STRUCTURE. Huntington: Robert E. Krieger Publishing Co., Inc., 1972.

Zuk, William. KINETIC ARCHITECTURE. New York: Van Nostrand Reinhold, 1970.