Surface Space - digital manufacturing techniques and emergent building material

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Bachelor of Arts in Architecture
University of California, Berkeley, CA 1998

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, February 2002.

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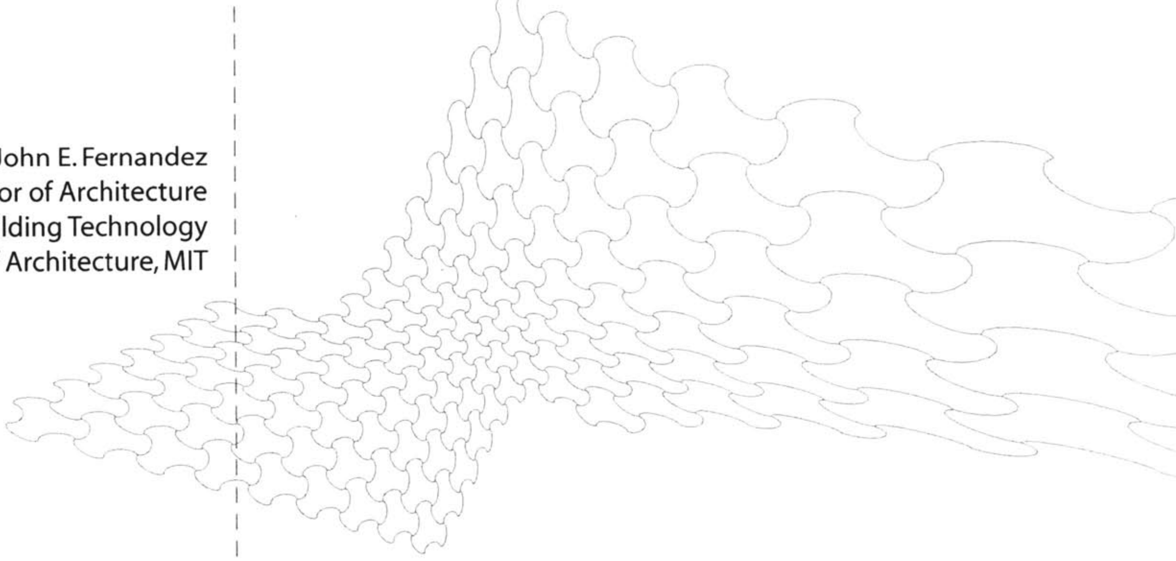

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abstract

This thesis explores tectonic possibilities of new material and forming techniques. The design process is catalyzed by experimenting different configurations of the material. This project attempts to develop inventive ways to use polymeric material. Incorporating both digital and hand based tools, the project will focus on the process of casting and molding polyurethane based rubber.

Instead of looking at the macro level of a building, the thesis should be viewed as a research based project that investigates assemblies at the domain of building surface. Based on this premise, the goal is to find how the tectonic expression at the scale of architectural details can inspire creative use of the material.

The framework of this thesis should be regarded as an open-ended process of discovery. Future research and innovation can be continued with respect to similar focus. The goal of this thesis is to engage design problems from innovations of material and techniques.

Thesis Supervisor: J. Meejin Yoon
Title: Assistant Professor of Architecture

acknowledgements

I sincerely thank everyone that has helped me through this thesis research.

I am grateful to my advisor, J. Meejin Yoon, for her encouragements throughout the project. Her faith in my project has kept me going through frustrating times. Her insights and sensibility have been very valuable to the progress of this thesis.

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Joy Hou - for sticking with me through thick and thin.

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Finally, I give my deepest appreciation to my parents for their unconditional love, patience, and support.

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introduction

Conceptual Framework

Innovation and Material

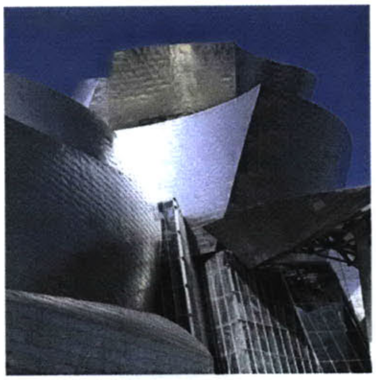


Fig. 08-1: cladding of Guggenheim

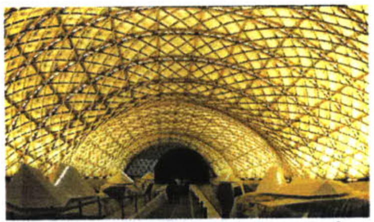


Fig. 08-2: paper tube roof structure of Japan Pavilion by Shigeru Ban


Fig. 08-3: Blur Building at Swiss Expo

Within the last few decades of the 20th century, vast varieties of new materials have been wide
introduced to the construction industry. Advance manufacturing technologies and material sc
developments have amplified the capacities of traditional architectural materials, furthermore,
discoveries of synthetic materials such polymers and composites have been added to the voca
of contemporary architectural materials. From building structural components, to cladding an
ing, the rapid advances of contemporary materials are evident in almost every aspect of constr

Across the contemporary building designs, new material emerges such as the shinning titaniu
used in the Guggenheim, and its custom made curved steel structures. The innovative use of S
Ban's recycled paper tubes for building structures. And the media pavilion for Swiss Expo 200
Diller and Scofidio. There are numerous exemplary works by those who engage themselves w
innovative use of both synthetic and traditional materials.

Consequently, this material explosion has strengthened the attention to "materiality" in the dis
of architecture. As a trend, the conception of "materiality" becomes increasingly influential for
designers as the fundamental basis of being innovative in their proposals.

However, the term "materiality" has been continually interpreted loosely upon designers' perso
sensibilities towards the definition of the "true nature" of materials. In fact, one would argue th
the use of the term "has come to mean all things with respect to the physical nature of a desig
proposal." (Fernandez, 2000) As Fernandez further argues that, while this notion of "materiality
does heighten the integrity and sensibilities towards the use of materials; a mere familiarity wi
material is not enough to allow for a understanding of full sets of parameters that promotes c
use of materials.

l Design and Manufacturing

with the growing popularities of new building materials, contemporary construction methods chniques, which usually involves digital means, have also became a new area of investigation h practitioners and academic researchers. As many designers and engineers now shifted aper drawings onto digital platforms, design processes between different industries are ever nterrelated. Architects have begun to learn from other disciplines where the digitally aided ses have become paradigms. For example, many projects from Frank O. Gehry's office are the of working closely with craftsmen and technologies originally from the automotive industry.

t of making innovative design proposals, architects are now fascinated with the possibilities d by CAD/CAM tools. In architectural design, computer software packages are most com- used for representational purposes, i.e. visualizations and construction documents. Until ly, digital tools have begun to be engaged by architects as form-generative means. For t, research projects by Greg Lynn's Form, and Bernard Cache's Objectile incorporate the pro- nability of CAD software and CNC (computer numeric control) machineries to create meaning- ms.

gh the use of digital technologies is still a debatable topic in terms of being a major influence evolution of architectural form, designers need to take active role to understand the benefits d by these technologies. In general, digitally aided design and manufacturing technologies designers and craftsmen to make more precise complex shapes and smooth curvilinear forms. mportantly, these tools offer designers to quickly turn complex proposals from the virtual into physical prototypes.

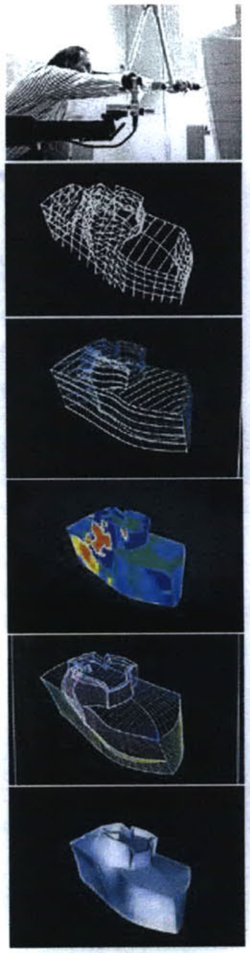


Fig. 09-1: CATIA process of design for Buggehneim Museum Bilbao

Synthesis

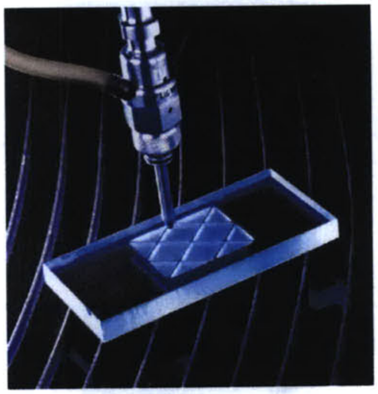


Fig. 10-1: glass milling

Fig. 10-2: metal milling

Considering the brief analyses in previous sections, this thesis interrogates the notion of "mat and "tectonics" in regard to synthetic material and digital technologies. The project strives fo tive moments within an explorative process. Contemporary designers interested in new mate need to expand their knowledge beyond generalized properties and stylistic aesthetics of m and familiarize themselves with the mechanical and physical properties by working directly the material.

Although the standardization of material and construction may be inevitable because of soc economics concern. From the perspective of architecture discourse, the main objective rema be the signification of materials and methods in respect to "tectonic". For example, architect as Frank O. Gehry's office, has begun studying concepts of mass customizations in manufactu for building parts using reconfigurable molding-building methods. Such studies allow not more freedom in form making of the end products, more importantly, this kind of research p the discoveries of new tectonic possibilities of the material.

In order to challenge today's established and standardized construction methods, one needs understand the economic and technological forces that shape the standards. This thesis adv that innovations stem from the empathy of material and its construct, therefore, need to tak in both the manufacturing processes and the end products.

tives

hesis proposes research and development for a set of new techniques and design processes to
ge synthetic material in architectural design. In particular, a polyurethane-based rubber of the
osetting elastomer category is investigated. The project should be developed on the premise
understanding the "synthetic nature" of the material with respect to its science; (2) exploring
ctonic possibilities and taking advantages offered by rapid prototyping and manufacturing

f the goals for the project is to address the "material nature", that is, the physical and mechanical
rties. These properties should be conceived in the design proposal through discoveries from
paper-based study, and physical interaction with the material. In other words, the design
sals need to be "material specific." Instead of looking at the macro scale of a building, the
t will focus on the domain of surfaces and details. Within this domain, the unique characteristic
tomeric material should be articulated both formally and functionally.

ition, this thesis explores digitally aided design and manufacturing techniques for building
blies. In respect to the design process, the project will address the relationships and conse-
es of prototyping, manufacturing and constructing. The project attempts to define a position
grate computer-aided tools into the design process.

, the design proposals of this project should be regarded as results of an open research
work. The framework respects the conditions of existing interventions of similar materials in the
ry, and can be expanded for possibilities of future innovations.

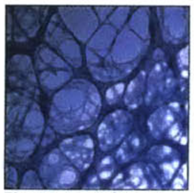


Fig. 11-1: polymer fibers viewed by TEM


Fig. 11-2: polycarbonate


Fig. 11-3: gaskets (automotive industry)


Fig. 11-4: o-rings (industrial use)

Methodology

"Experimental invention: a process in which the designer catalyzes the process of discovery th empirical work within the context of a laboratory-workshop. This mode of discovery necessita mentioned above, a space in which to work with the material, experiment with a variety of co tions, attempt several processing ideas, and design prototypical assemblies. As part of this sp is absolutely necessary that the designer also have access to experimental equipment that ha capacity to test the material in a variety of modes." (Fernandez 2000)

The above paragraph taken from the essay, "Material Readings", inspires the mode of explorati this thesis. Base on this concept, the general framework is outlined in the following fashion.

1. In preparation, a combination of scientific descriptions for the material is inquired. Readings on the fundamental logic of CAD/CAM processes will be conducted.
2. As source of design inspiration, morphologies of variable systems in nature, such as water ripples and waves of sand dune, are examined.
3. The project will attempt to identify the parameters that determine shaping forces i natural science. The objective is to draw relationships to the physics behind the de proposal in terms of how the material interacts with the mold.
4. While the initial experiment relies heavily on personal intuition and speculation, knowledge accumulated from testing different material configurations will serve a basis of the project.

methodology


Fig.13-1: Merritt Extruder (polyruathane production for medical use)

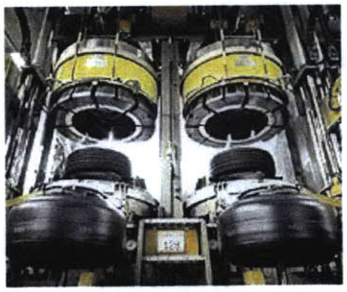


Fig.13-2: tire production


Fig.13-3: injection molding (polymer processing)

aterial research part of this project includes polymer and elastomer's scientific descriptions s natural properties, and processing procedures. This part will also examine applications and t in the building industry as well as other platforms. Series of readings will be conducted to esize the premise for material selection and manufacturing. The research should also examine d knowledge in other design industries.

ard to the design tools, the project will place emphasis on the integrations of computer- design and computer-aided-manufacturing tools into traditional design processes. However, nphasis on digitally aided design tool should be conceived as aids for the designer to more ntly analyze, visualize and realize the project. The goal of integrated CAD/CAM processes is to for more accurate, and sophisticated testing of the design at various stages, and consequently ng higher quality of production.

Tools and Processes

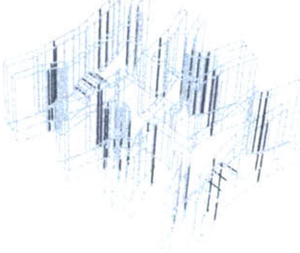
Hand

Ideas are first generated from sketches of speculative conditions. This prescribes the initial m different material configurations. Sketches are refined to the level of detail, which can then b translated into working drawings in CAD.

CAD/CAM

From the sketched ideas, prototypes of mold are made with combinations of CAD/CAM tools. CAD models are made to visualize and determine the technique of prototyping. For some pr depending on the complexity level, sketches may be translated directly into 2D CAD drawing will be used for laser cutting. During the process of CAD input, modifications of the original i are implemented.

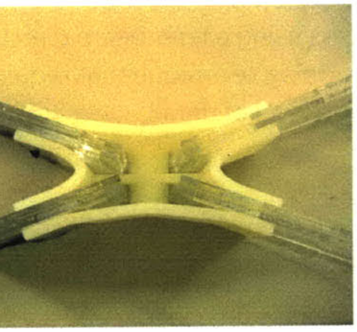
By working with rapid prototyping techniques, the conventional model building process duri design is replaced with building working prototypes. Although the exclusion of building mo require higher level of accuracy when design, the approach allows for direct interactions with material. Rather than using representational materials, this process is very important to serve of this thesis - making discoveries of techniques inherent of the material properties.

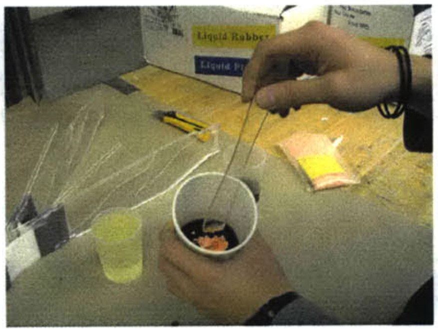


ng and Casting

old materials are selected based on ease of use and casting requirements of the elastomeric ne. The mold materials used in this project are acrylic based plexi-glass and thermoplastic er of stereo lithography (3D printer). These materials have very good durability, high melting at the temperature of laser beam) and are relatively easy to remove after the casting cures.

mold prototype is assembled, the rubber is mixed and poured at room temperature in a ted environment. The casting and curing are based on the mixture of a two part chemical, and e no additional procedures. During the casting process, pigments of color or luminescent mate- n be added to the chemical mixture to alter the aesthetic qualities of the finished products. uring techniques such as heating and coating can also be applied to enhance resiliency and lity.





CAD/CAM software and machinery

Computer Aided Design

AutoCAD 2000 by Autodesk: an industry-standard 2D drafting software for producing work drawings for laser cutting; the software is also capable for building simple 3D models.

FormZ 3.8.0 by Auto.des.sys: a complete 3D modeling and rendering software package.

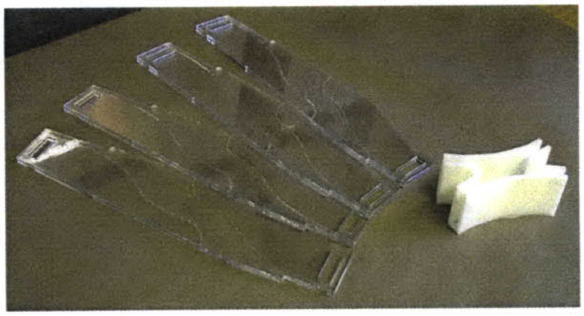
Computer Aided Manufacturing

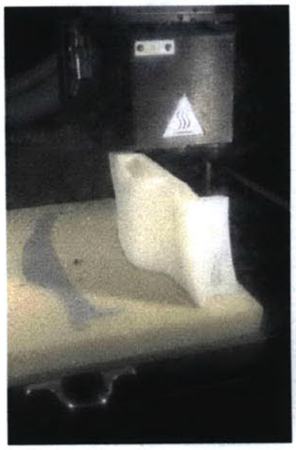
Stereo Lithography

Best know rapid prototyping system in the industry. Stereo Lithography is a 3d printing process using a laser beam direc computer onto the surface of a photo-curable liquid plastic. This process is a thermoplastic forming technique that requi operating temperatures. Multiple copies of solid or surface models can be produced with high level of detail.

Process

1. 3D model of solid or surface is input from CAD to the operating software, which then cuts it into slices.
2. Elevator (beam) is located at distance from a layer of liquid equal to the thickness of first slice.
3. The laser beam then follows contour of first slice.
4. The liquid is photo-polymeric, when exposed to UV laser beam; the liquid solidifies by low energy absorp
5. Each subsequent layer is made.
6. There is supporting apparatus during building process.





tages
uous 24 hours unattended operation
esolution
lly any geometric shape, three dimensional cavities can be made

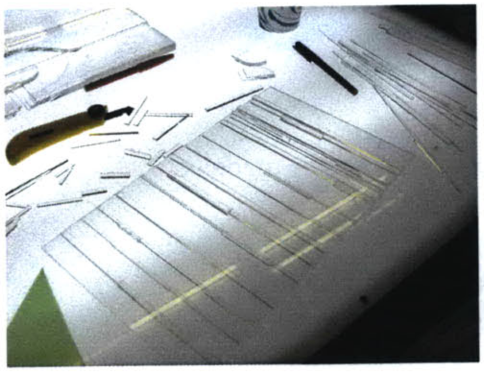
vantages
sticated sequence of process, and complex setup procedures
acy less then mechanical part manufacturing
conomical

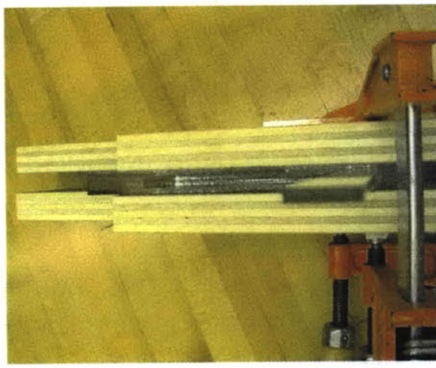
Laminated Object Manufacturing

Manufacturing 3D objects based on 2D geometrical data. This technique uses sliced data to control laser to cut the contours of materials. The sliced material will then be glued together and the desired model is created layer by layer.

Process

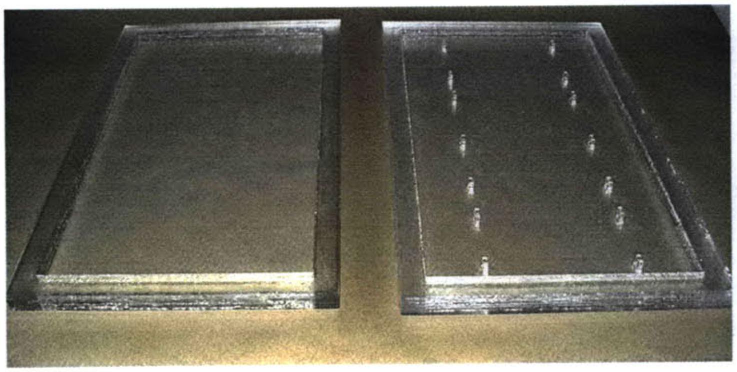
1. after 3D CAD model is built, slice the model into 2d sections, with each section's thickness equal to that of the r
2. desire material needs to be prepared in planar format
3. two mirrors guide the co2 laser beam to cut the material
4. laminated part is grown on surface that can be vertically adjusted
5. the finished product is like a block, the scraps can be sanded off
6. additional polishing may be required

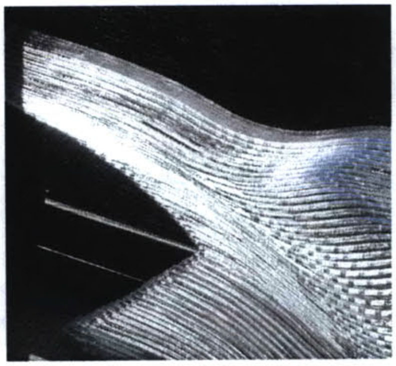




tages
to cut variety of organic and inorganic material such as paper, plastic, ceramic, composite, etc....
ely low cost compared to other rapid prototyping methods
s much faster then competitive techniques
ess internally to cause deformation
uited to build large parts

vantages
ural integrity can be influenced by the strength of glued layers
es laborious rebuilding after each layer is cut
parts like bottles, cannot be built





Polymers

Polymers are used for almost an infinite number of purposes. New applications are constantly being developed. Towards the last decades of the 20th century, many macromolecular compounds have become construction materials just as are ceramics, metals and wood. In applications where smaller objects are created, polymeric material rivals the metals in a variety of ways.

Many polymeric materials are as readily machinable as metals. In production of finished plastic items, metal-forming techniques such as cutting, drilling, etc., are very common. Methods of joining polymeric materials, applying adhesive bonding, are as common as the analogous welding operation applied to metals. Since forming methods of polymers are not confined to solid or liquid state, but can be extended to non-rigid fluid material, the variety of forming techniques is greater than with metals.

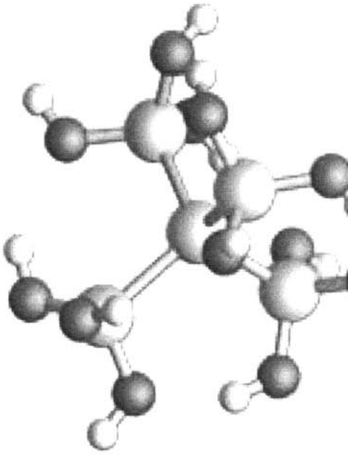
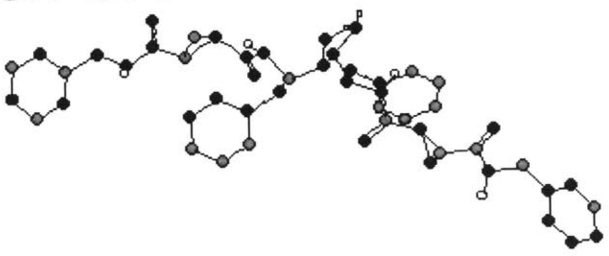


Fig. 20-1 & 20-2: molecular structure of polymer

Scientific Definition

Polymer is based on a large number of small molecular units, called monomers. The chemical process of polymerization combines the monomers together. This result of this process is long-chain molecules, called polymer. Natural materials such as bitumen, rubber, and cellulose possess this type of structure.



Categorization

1. Thermoplastic polymer:

Substance consisting of a series of long-chain molecules polymerized in a way that all chains of the molecules are separate and can slide over one another. The unconnected linear chain structure allows repeated cycle of softening and hardening by heating and cooling, respectively. Thermoplastic polymers can be formed from one shape into another. In concept, this procedure could be repeated indefinitely. However, in practice, the polymer is subject to degradation at high temperatures, limiting the number of times it can be processed with retained useful properties. Thermoplastics can also be dissolved with a suitable solvent. In both processes, after melting and cooling and after dissolution and precipitation, the chemical composition of thermoplastic material is nominally unchanged.

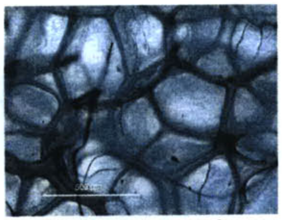


Fig.21-1: thermoplastic foam processing

2. Thermosetting polymer:

Polymers cross-linked into one giant molecule. After cross-linking into a three-dimensional network structure, they cannon be melted or dissolved. Only swollen by suitable solvents to form gels. They can be destroyed, thermally, chemically, or mechanically, into compounds of composition. However these compounds are structured differently from the starting material. Thermoplastics may be converted into thermosets, but the reverse is not possible. A vulcanized rubber tire is an example of thermosetting polymer. The rubber can be burned or ground up, but it cannot be returned back to the liquid state to fill a mold.


Fig.21-2: hot melt (or solvent) prepeg machine

3. Foamed polymers:

A system of a gas dispersed in a solid polymer before molding of the molten resin. This is achieved by adding to the resin formulations a chemical blowing agent. This agent releases a gas which causes the polymer to expand, increasing its original volume many times by the formation of small gas cells.


Fig. 22-1: DuPont Elvaloy® AC foam

Depending on their chemical compositions and consequent physical structures, polymers are familiar to us as elastomers, plastics, fibers, composites, coatings, adhesives, etc. These are the more general classifications of polymers. However, there is considerable overlap in this classification. Elastomers, such as natural rubber (polyisoprene), will act as plastics at very low temperatures, and fibers, such as nylon, can be used as molded plastics.

Rigid plastics and fibers are characterized by high moduli, whereas elastomers undergo large reversible elongations under applied stress. When stress is applied against strain, the slope for fibers and rigid plastics will have low values; that is, they have a high modulus. In contrast, the elastomers will undergo reversible elongation when stretched.

hysical and mechanical properties

he physical and mechanical properties of polymeric materials vary depending on chemical mixtures. A characteristic feature of olymer is the greater or lesser degree of chain flexibility, depending on chemical structure. The chain conformations of polymers re almost always different in solution from what they are in the dry solid state. The changes in chain conformations induced by he presence of a solvent in various concentrations not only change its properties but also provide a valuable degree of freedom n characterization of the polymer. General and specific interactions in solution affect chain conformations in predictable and neasurable ways. Therefore, specific properties can be developed through varying the chemical structure.

n general, properties of polymeric material can be classified in the following two categories:

Nonmetallic properties - function of forming a chemical bond by sharing electrons:
low specific gravity, low conductivity, transparency, and resistance to corrosion, extent of interactions among polymer chains to create different physical and chemical properties, such as differences between plastics, fibers, elastomers, etc.

Metallic properties - function of presence of fluid electrons:
luster, electrical conductivity, malleability, and ductility

rom a structural point of view, polymers exhibit poor mechanical behavior when under load. The mechanical behavior of olymers is highly dependent upon the magnitude, the time, the rate and the frequency of load application. Temperature also lays an important factor. Both thermosets and thermoplastics possess similar range of tensile strength and Modulus of elasticity, vith slight variations among materials. Thermoplastic polymers do not withstand compression.

dvantages of polymer over conventional materials

light weight
resilience
resistance to corrosion
ease of processing
can be combined with fibers to form composites with enhanced properties

Elastomers

Definition

Elastomer is most commonly known to us as rubber. Elastomers, members of the polymer family, are defined as materials consisting of long-chain molecules, coiled and twisted in a random manner.

Properties

The unique property of elastomer is its flexibility such that the material is able to undergo very large deformations. However, in the uncured state the elastomers are unable to recover completely from large deformations due to the sliding of the molecules over each other during load. After a curing process, known as vulcanization, the molecules are cross-linked and held firmly together. Vulcanization is similar to the cross-linking of thermosetting polymers. As the vulcanization prevents sliding of the molecules relative to each other but does not change the form of the coiled molecules, the elastomeric material will completely recover its original shape after the removal of a force.

The advantages of vulcanized rubber are similar to those of polymers:

resilience
flexibility at low temperatures
resistance to oils, greases, ozone and many acids and bases

new family of thermoplastic rubber has been developed (commercial synthetic ubber). The advantages of these over the conventional rubbers are:

1. materials can be melted and molded more easily
2. greater freedom in chemical composition. solutions can be varied in order to produce a novel range of properties, making the material adaptable to wider variety of use

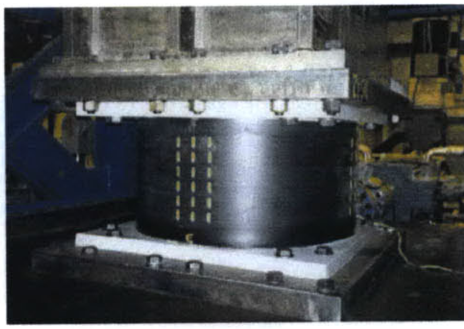


Fig.25-2: application in construction industry: bearing for seismic purpose

Fig.25-1: high deformability/elasticity

Composite materials

Definition

Materials made from two or more components. The combinations are generally of a low modulus, low strength material (e.g. a thermosetting resin, a thermoplastic resin, or an elastomer) with a high strength, high stiffness reinforcing- fibre martial. Most commonly used types of fibre are glass fibre, carbon fibre, and Kevlar.

In the building industry, the most common fibre used in composite materials is glass fibre. However, carbon fibre is used to increase the stiffness of the structural member. Carbon fibre composites can also be used partly in an area within the structure. This allows the stiffness to exceed the value by using glass fibre. Kevlar fibres are the strongest, and can be used when extra stiffness is needed.

Another common composite used in construction is polymers and fillers. Polymers can be combined with fillers to improve their mechanical or physical properties. The fillers usually consist of wood flour, china clay, quartz powder or other powdered minerals. In general composite materials also have very low coefficient of thermal expansion, making them structurally stable.


Fig. 26-1: woven roving


Fig. 26-2: Kevlar® Tapes

perties

ilar to synethetic polymeric materials, composite materials can be formed in a variety vays. Therefore, physical and mechanical properties of the composites are highly endent on

- relative proportions of fibre to matrix and the fibre orientation within the matrix material
- components used
- method of manufacture

Processing techniques

Materials made from polymers are usually fabricated with the use of dies or molds, by melt process, or by solution casting. Therefore, the physical contact with tools is an important factor in determining finished surface properties, i.e. smoothness and texture. During the production process, annealing, curing, and heat treatment also affect surface topography, morphology at the molecular level.

Once a polymer with the right properties is produced, it must be manipulated into some useful shape or object. Various methods are used in industry to do this. Injection molding and extrusion are widely used to process plastics while spinning is the process used to produce fibers.

Common techniques of production

Molding / injection molding

Molding and/or injection molding is the most widely used forms of polymer processing. Polymer at the liquid state is poured or injected into a mold which usually made of metal or other polymeric materials. In injection molding process, polymer is heated above its glass transition temperature, and then forced under high pressure to fill the contents of the mold. The molten polymer usually squeezed into the mold by a ram or a reciprocating screw. The polymer is then allowed to cool and is then removed from the mold in its final form. The advantage of injection molding is the speed of mass production, since the process can be performed many times per second.

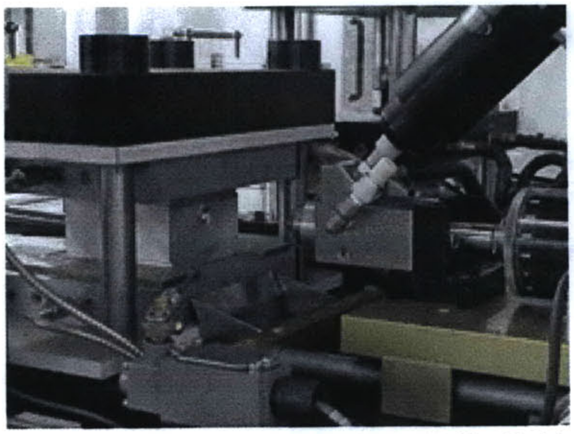


Fig. 28-1: Liquid Silicone Rubber (LSR) Injection Molding Machin

Extrusion

Extrusion process is similar to injection molding except that molten polymer is forced through a die rather than into a mold. However, one of the downside of extrusion is that the finished product must have the same cross-sectional shape. Example of product from extrusion is plastic tubing and hose.

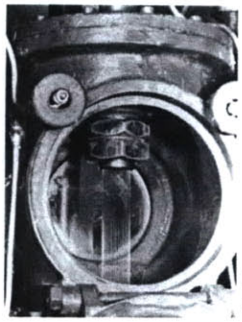


Fig. 29-1: extruders producing continuous cylinders of polymer or fine filaments

Spinning

Spinning is the general process to produce polymeric fibers. There are three main types of spinning: melt, dry, and wet. In general, melt spinning is used for moldable material such as polymers. Dry spinning involves dissolving the polymer into an evaporative solution. Wet spinning is used when the solvent can only be removed by chemical means. The three types of spinning are operated with on same principle. A mass of polymer is heated to the liquid state. The molten polymer is then pumped to the face of a metal disk, the spinneret which contains many small holes. The filaments, thin streams of polymers that emerge from the holes, are wound together as they solidify, forming a long fiber. The spinning process can be operated up to the speed of 2500 feet/minute. Following the spinning process, a stretching procedure is applied to the fibers. Stretching usually goes up 3 to 8 or more times than their original length to produce increased chain alignment. This process enhances the crystallinity in order to yield improved strength for the fibres.

Fig. 29-2: spinning machines

General applications of polymeric materials

> "Macromolecular science has had a major impact on the way we live. It is difficult to find an aspect of our lives that is not affected by polymers. Just 50 years ago, materials we now take for granted were non-existent. With further advances in the understanding of polymers, and with new applications being researched, there is no reason to believe that the revolution will stop any time soon."

market and applicati

Application by typology

Elastomers

Rubber is considered the most important of all elastomers. Rubber is originally found as a natural material obtained from the bark of the rubber tree. The natural rubber is a polymer that has repeating units of isoprene. For many centuries, humans have used natural rubber for many different purposes.

Styrene-butadiene rubber (SBR) is a synthetic variety that makes up most of the rubber used in the US today. This material was developed during World War II under government control. Today, the United States consumes on the order of a million tons of SBR each year through private manufacturers. In the building industry, elastomeric materials are generally used for sealing, insulating, and laminating purposes.

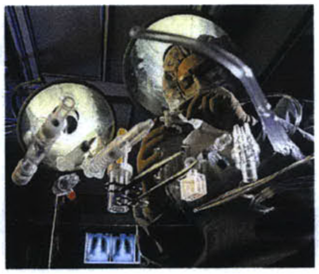


Fig. 30-1: Clear, shatter-resistant, non-toxic K-Re
rene-butadiene copolymer is ideal for medical

Fig. 30-2: styrene-butadiene rubber (SBR) prov
properties today's tire products manufacturer

lastics

pplications of plastic based products are the widest
mong the polymer family. Approximately 60 billion
ounds of plastics is consumed in the US each year. The
nost important and versatile of commercial plastics is poly-
thylene. Polyethylene can be produced in many different
orms. The first type of polyethylene that was commercially
xploited is low density polyethylene (LDPE), or branched
olyethylene. The major characteristics of LDPE are its soft-
ess and pliability. Applications of LDPE range from plastic
ags, containers, textiles, electrical insulation, to coatings
or packaging materials.

he high density polyethylene (HDPE) or linear polyethyl-
ne is much more rigid than branched polyethylene. This
naterial can be used where rigidity is important. Common
pplications of HDPE are plastic tubing, bottles, and bottle
aps.

ther forms of this material include high and ultra-high
nolecular weight polyethylene, HMW and UHMW. These
naterials are used in applications where extreme tough-
ess and resilience are necessary.

lastics-based products are very commonly used in archi-
ectural application. Various building components are now
abricated with polymer-based material. From glazing to
tructural composites, polymeric materials exhibit varieties
f properties in contemporary building design.

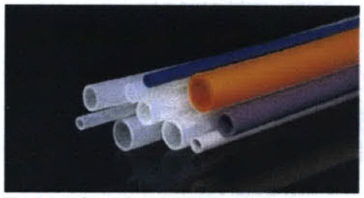


Fig. 31-1: low density polyethylene tubing

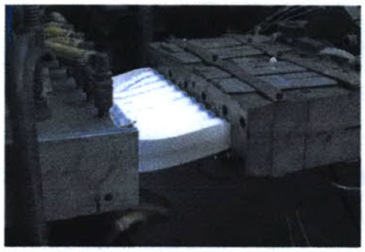


Fig. 31-2: extrusion of LDPE


Fig. 31-3: Polyethylene sheet

Fibers

Humans have been using natural fibers such as cotton, wool, and silk for many centuries. It wasn't until 1885, when the first artificial silk was patented, had the age of synthetic modern fiber begun. Contemporary material science has developed synthetic polymers hat possess desirable characteristics, such as a high softening point to allow for ironing, high tensile strength, adequate stiffness, and desirable fabric qualities. These polymers are then formed into fibers with various characteristics. The combination of strength, weight, and durability has made the synthetic fibers, such as nylon, polyester, rayon, and acrylic, important materials in many different applications.


Fig. 32-1: Filter e
for chemical an
applications

For example, nylon (a generic term for polyamides) is one of the most popular polymer for synthetic fibre. Nylon, known for its strength, elasticity, toughness, and resistance to abrasion, has commercial applications including clothing and carpeting. Nylon has special properties that distinguish it from other materials. One such property is the elasticity. Like other synthetic fibers, Nylon has a large electrical resistance. This is the cause for the build-up of static charges in some articles of clothing and carpets.


Fig. 32-2: nylon

As the technology advances, new generations of stronger and lighter materials can be produced. These new synthetic fibres can be used in the building industry to replace structural components, and create new forms. From textiles to composites, synthetic fibers have become very important in both the technological and morphological aspects of contemporary architectural forms.


Fig. 32-3: Acryl
rayon

Investigated material and forming method

Compared to many natural materials such as wood, metal and ceramics, as expected, various types of polymeric materials have become as important in the building industry. Polymeric materials with their novel properties and capabilities to be free-formed into almost any shape are interesting aspects to this thesis.

Polymeric materials are based on chemical mixtures; and because of this unique synthetic nature, their properties such as structural strength, hardness, flexibilities and resiliency can be prescribed. Of thousands of possible combinations of resin, plastic, rubber and composites, this thesis proposes to investigate a polyurethane based thermosetting rubber. The selection is based mainly on its interesting forming method: a two parts component is mixed at a liquid state and solidifies at room temperature after filling into the mold.

Many of the synthetic polymeric materials share the same forming method. Although, this thesis has selected only one particular kind of elastomer, the goal is to develop a set of craft in regard to the forming method, so that the craft can be applied to other types of polymers with the same forming method. In the design proposals, the unique physical and mechanical properties of the rubber need to be addressed. In addition, the following list of criteria is considered:

Structural strength: tensile and compressive
Ease of casting and curing procedures
Flow rate with respect to mold design
Aesthetic quality of the finished product: transparency, tactile, color…etc.
Safety

Polyurethane Market

Future trends of polymeric material

Natural science has offered biological polymers as a choice of material. As material and chemical science advance, new discoveries and improvements of synthetic materials promise potential innovations in the future. In a wide variety of existing applications, polymer research is continually being developed in areas of: conduction and storage of electricity, heat and light, molecular based information storage and processing, molecular composites, unique separation membranes, revolutionary new forms of food processing and packaging, health, housing, and transportation. As a matter of fact, polymers have been and will play an increasingly important role in all aspects that affects our lives.

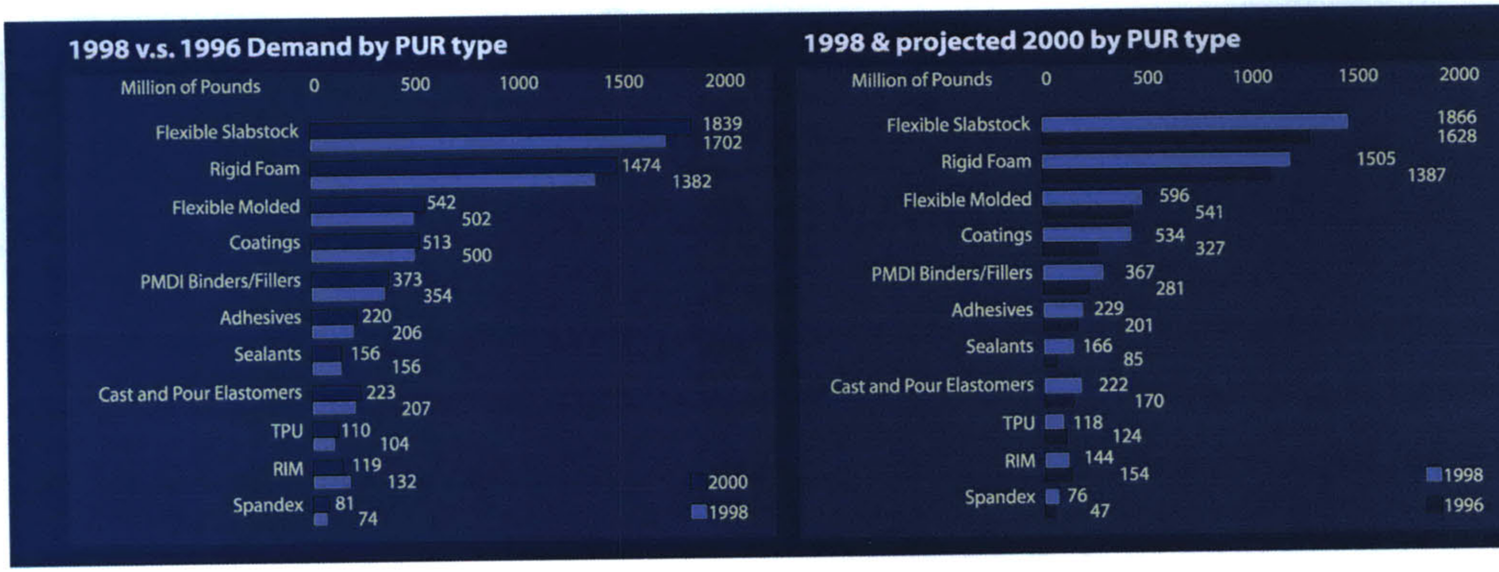


Fig. 34-1: Polyurethane (PU
projected market by type

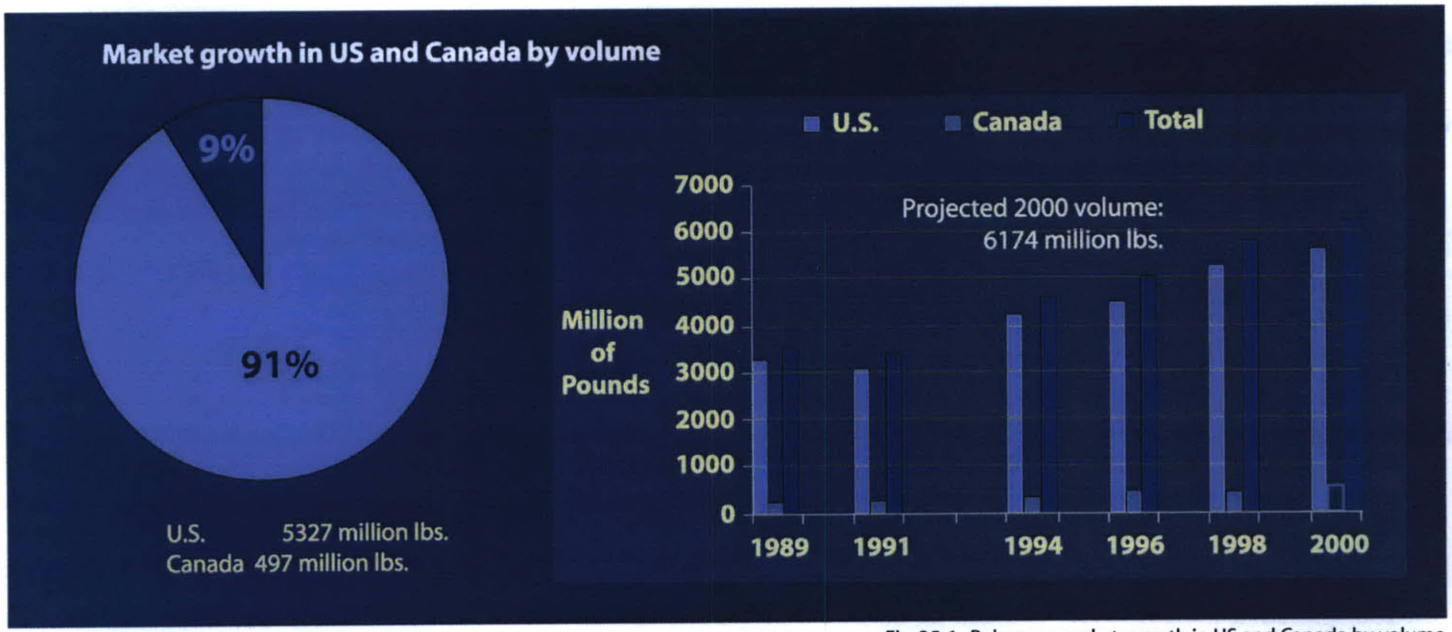


Fig. 35-1: Polymers market growth in US and Canada by volume

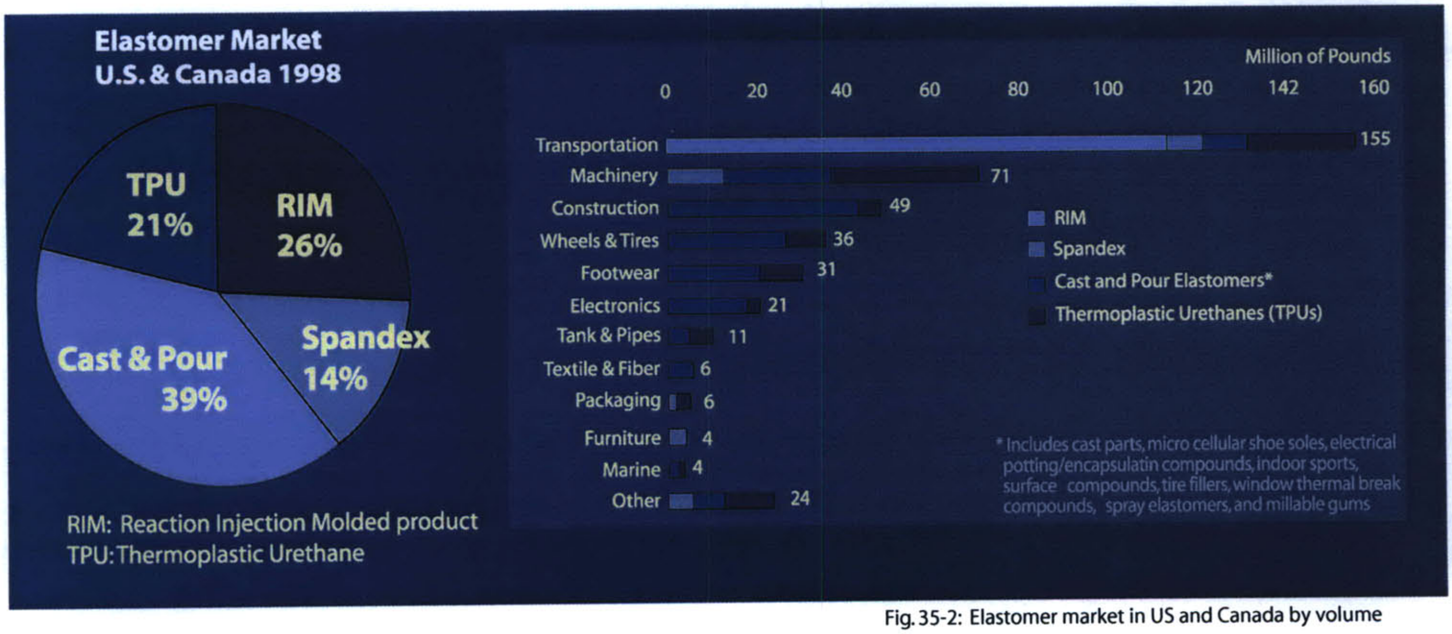


Fig. 35-2: Elastomer market in US and Canada by volume

Recycling techniques for polyurethane

Mechanical recycling

This method is based on the regrinding industrial and post-consumer flexible polyurethane foam into powders. The result of regrinding can be used in the production of new foam. The recycled flexible foam bonding yields a variety of padding products. The recovered pieces of flexible polyurethane foam can be made into carpet underlay and athletic mats.

Adhesive Pressing

This is a technique where polyurethane granules are surface coated with a binder. During the curing stage, heat and pressure are applied to make contoured parts such automotive floor mats and tire covers.

Compression Molding

Similar to adhesive pressing, this process offers another way to produce rigid parts where polyurethane granules are molded three dimensionally. Molding polyurethane granules can be recycled into building or automotive components such as pump and motor housings.

ergy recovery methods for polyurethane

vanced material science and technologies have proven that recycled polyurethane can be converted into valuable ergy. The inherent energy value of polyurethane can be totally recovered.

experiments conducted in the US, flexible polyurethane foam was added to common municipal solid waste at the el up to 20% by weight. The results of this method show that though the furnace operation and ash generation nained at the same level, emissions were under operating limits. More importantly, polyurethane feedstock genered significant BTU (British Thermal Unit) value, which consequently reduces the consumption of fossil fuel in the ocess.

erseas, the ISOPA (European Isocyanate Producer Association) continues to support carefully controlled incineration th flue gas cleaning technologies. Countries like Switzerland, Sweden, Germany and Denmark are practicing this chnique to generate up to 10% of domestic electricity requirements. Energy recovery technology for polyurethane ncreasingly being considered as an acceptable recovery option. The following methods outline some general tegories of technologies among the hundreds of patents being developed:

Glycolysis
This is a process where post-consumer polyurethane scraps are reacted with diols at high temperatures to produce a key raw material, polyols.

Hydrolysis
This process produces both polyols and amine intermediates, from recycled polyurethane. These elements are both key chemical parts as raw material for polyurethane. After recovery, polyols can be used as effective fuels; and amine intermediates can be reused to produce other polyurethane components.

Pyrolysis
Under a heated and oxygen free environment, this process breaks down recycled polyurethane and plastics into gas and oil.

Hydrogenation
Similar to the result of pyrolysis, hydrogenation produces purer gases and oils under heat and pressure with hydrogen.

Design concepts

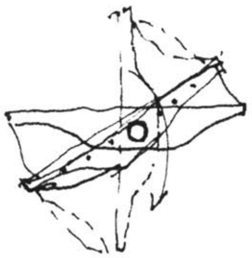
design concepts

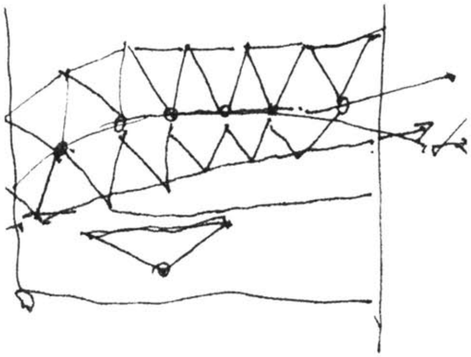
Developments from material readings

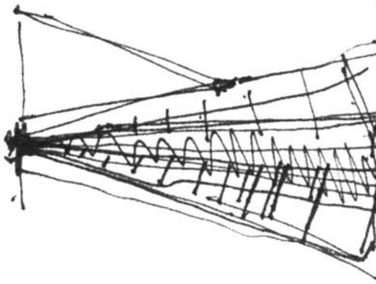
A variety of joining techniques, using commercial synthetic rubber, was explored in this thesis project. A rubber joint might not act as an adhesive, but it is sufficiently resilient to accommodate relative movement of the structural members caused by expansion, contraction, vibration, and other differential stresses.

The characteristics that define these joints are:

they should be easily deformable during application and in service
they absorb cyclic movement without permanent distortion: possessing recovery properties (shape memory).
the properties should not vary greatly across the service temperature range (i.e. no expansion nor contraction)
they should be durable







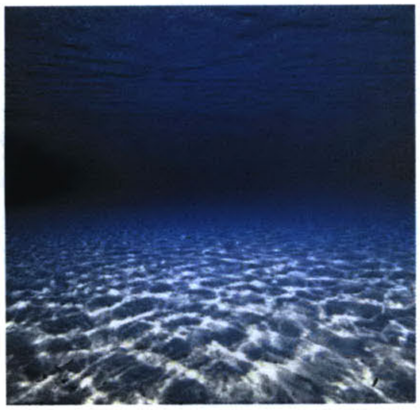
ation from natural Phenomenon

hology of dynamic systems in nature

The logic behind the patterns and forms generated by the interaction of natural forces.

The waves, so-called bedforms that occur when a fluid flows over loose sedimentary material. They occur all over the world under many different conditions and produce a magnificent variety of shapes and patterns. Some of them remain stationary, such as the diamond-shaped patterns sometimes seen on a dry beach. Others, such as sand dunes in the desert, move in the direction of the prevailing wind or current.

Ripples in sand, found on both beaches and dunes, are one of nature's most ubiquitous and spectacular examples of self-organization. They do not result from some predetermined pattern in the wind that is somehow impressed on the surface, but rather from the dynamics of individual grains in motion across the surface. They arise whenever wind blows strongly enough over a sand surface to entrain grains into the wind. The subsequent hopping and leaping of these grains is called saltation.



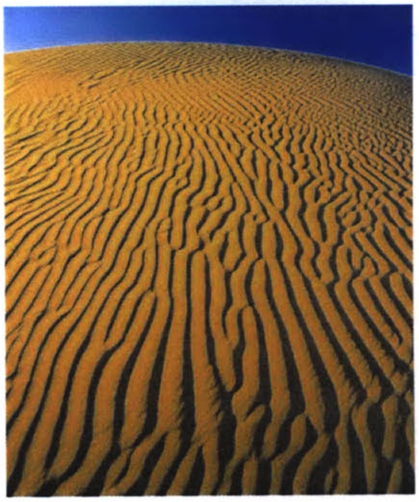


Fig. 39 -1, 2 & 3: photographs of
(1) underwater reflection
(2) cloud pattern
(3) desert landscape

Interaction of fluid dynamics

Water waves arise when pressure from the wind starts a pressure hump, which passes on its energy to adjacent water molecules in the direction of the wind. As the wind speed increases, the waves become regular and 'march' along the surface at predictable speeds and with predictable heights. Water waves away from shore become unstable when the wind speed exceeds 1.3 times the waves' speed. At that point, they begin to get steep and begin to break forward, producing whitecaps. The upwind slope then becomes shallower (flatter) than the downwind slope. The higher the wind in relation to the wave speed, the steeper the waves get, especially on the downwind side.

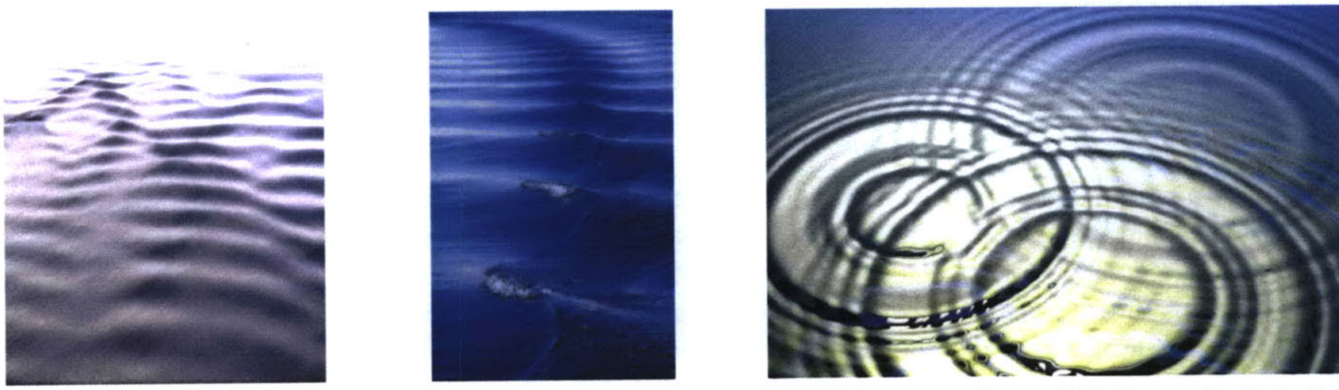
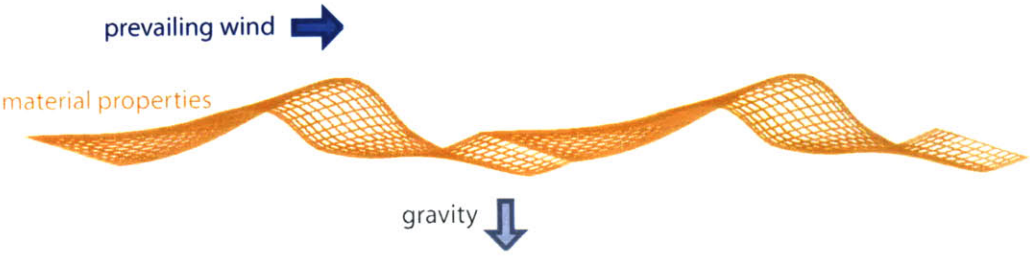


Fig. 40-1 , 2 & 3: photographs of water ripp

Granular material and fluid dynamics

Wind over sand behaves somewhat differently, but some of the same basic forces are at work to create regular spaced ripples. Because sand does not transmit energy to adjacent sand particles when wind blows over it, the wind must rise over a stationary hump. In so doing, it is compressed vertically, so it must speed up. The top of the hump (sand wave) and the windward slope get the greatest velocity. The valley between (where the wind can expand again) has the slowest wind; a rolling vortex, which acts as a vacuum to lift sand from the valley, arises there. A wind, or the wash along a shore, must be prolonged and continuous from one direction in order for sand ripples to form. In the Great Lakes region, sand ripples are best seen or felt underwater. They are fairly rare on the dry beach around here, probably because the local winds are very erratic and the sand is less sticky than ocean sand.

Fig. 41-1 & 2: photographs of desert landscape



Morphology of organic elements

The structural organization and fluid transportation of a leaf is worth investigating because of its complex integration at a detail level. Zooming into a leaf, one can see that the stem, main structural element, begins to transform itself into the smaller veins, which are then integrated into the thinner skin. This unique morphology between the two systems of rigid and soft, solid and fluid begins to inform how fluid and solid structures are integrated in mold design.

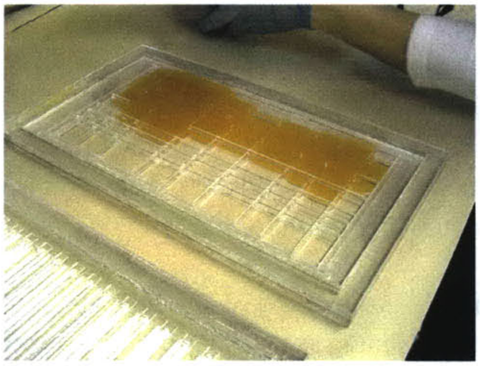
Fig. 42-1 & 2: Closeup photograph of leaf

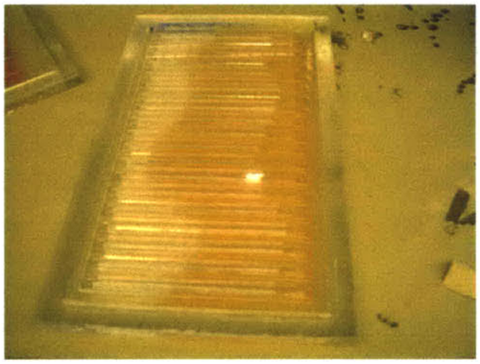
Material tendency and presence

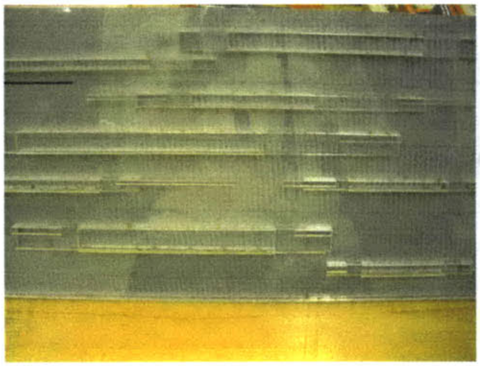
Thinking organically with the material is an important starting point for each exploration. This means not only reading the material's scientific and mechanical properties, but more importantly, the unique behavior of the material when it is shaped under the parametric factors such as shape of the mold vs. gravity, flow rate vs. pouring speed, mechanical vs. air pressure.

There are many important characteristics of the polyurethane rubber, amongst all, the change of physical states, that is, liquid rubber transforms process from fluid to solid state was considered as one of the most significant factor.

Other properties of the forming process of the material such as, pouring against the gravitational forces and the making of mold results in a trace of constructions: capture the interaction of the forces. Stretching and shape memory, how material deforms after curing.







Typology of joining techniques

1. **Mechanical Bonding**: joints formed by exertion of macroscopic residual compressive stresses between the components which maintain the intended geometrical constraint of the component within the engineering system during its operation. Assembly, and often disassembly, of components made from diverse materials is permitted

Fig. 44-1: this tapp
combines the high
and versatility of fa
steel with the tradi
and end gasketed
joint design

- a. seals and gaskets: Joints intend to "seal" or to transmit movement (sliding seals). They are a load-spreading element whose response to the compressive stresses exerted at a joint serves to accommodated dimensional mismatch
- b. fasteners
- c. mechanical joining systems: lock seams, screws and bolts, rivets,

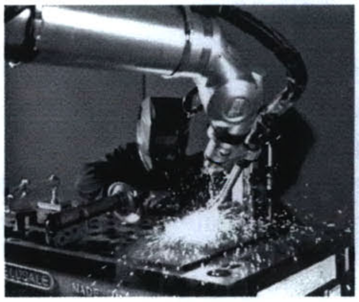


Fig. 44-2: welding

2. Welding: two components are joined by heating the region at the interface above the melting point (localized melting) of one or other of the components

3. Weld Metallurgy: welding of like materials, with primary aim to approximate selected engineering properties of the bulk components in the region of the weldment

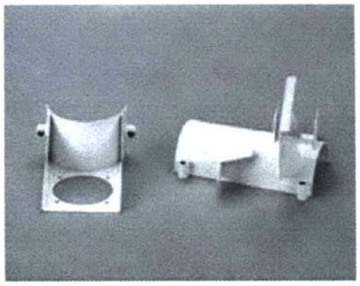
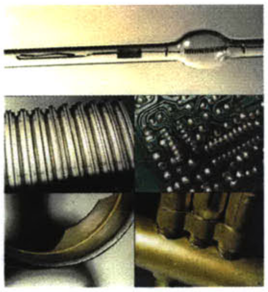


Fig. 44-3: welding
parts

1: from top and clockwise:
ance brazed light bulb fil-
a soldered circuit board, a
solenoid heat exchanger, a
ring housing, and a brazed
r heat exchanger



4. **Soldering and Brazing**: bonding processes which involve the use of a filler alloy with a melting range well below that of the components to be joined. These components are usually metallic, although ceramic components can also be bonded within the framework of these technologies.

2: Copper heat exchanger
ed by diffusion bonding

5. **Metal-Ceramic Joints and Diffusion Bonding**: bonding of metal and ceramic components and two ceramic components, respectively. Metal-ceramic joint is accomplished by introducing a ductile or compliant inter layer, by ensuring that dimensional tolerance requirements are met, by matching the thermal expansion characteristics of the components, or most commonly, by a combination of all these strategies. Diffusion bond depends on both thermally activated plastic flow and diffusion-controlled mass transfer.

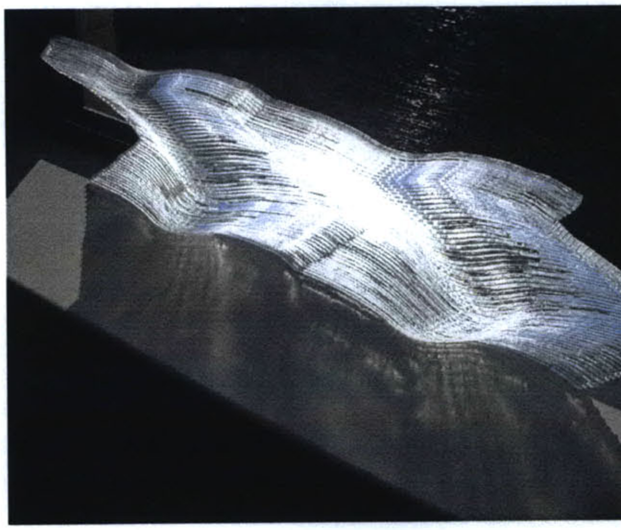
3: Advanced two-component
g polyurethane adhesive
designed to bond structural
usses to gypsum or wood
tes in ceiling construction

6. **Adhesives**: polymeric compounds applied at room temperature to the surfaces to be bonded, and may harden either at room temperature or after some further treatment: heating or irradiation.

** Polyurethane adhesives: commonly sold as two-component systems, consisting of the resin and a second component containing a catalyst. Polyurethane adhesives generally have better low temperature strength and toughness than epoxy resin. They are available with a wide range of elastic response (which includes both good stiffness and elastomeric grades).

design experiment

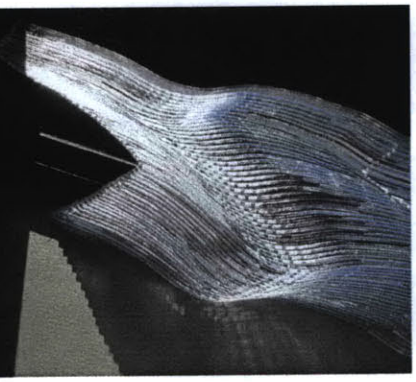
Wave Form

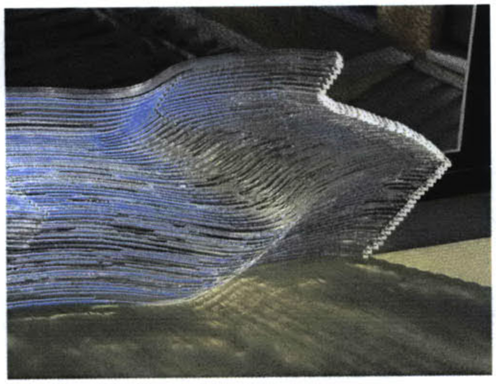


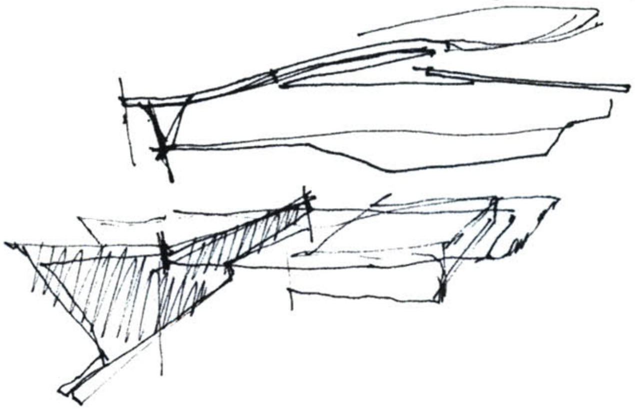
This design proposal is based on a sine curve, derived from the mathematics of water ripple frozen at a forzen moment. Using just one formula, multiple plexi-glass strips of the sine wave was laser cutted.

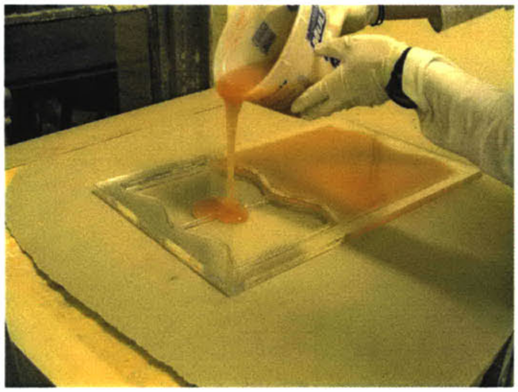
After each piece was generated, lamination in z-axis begins. During this process, each piece was altered in the x and y directions to create the final form of three dimensionally curved structure.

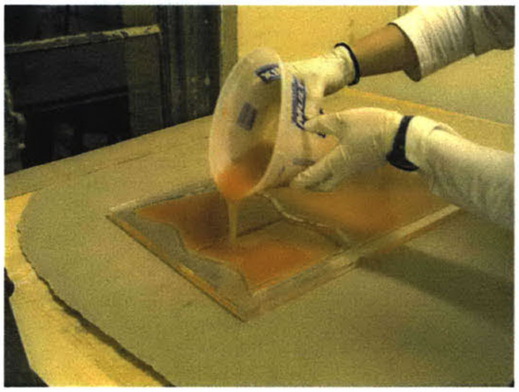
The goal of this experiment was to explore the inherent tectonic possiblities of the lamination process. From simply repeating a 2 dimensional object, complex shape can be created.

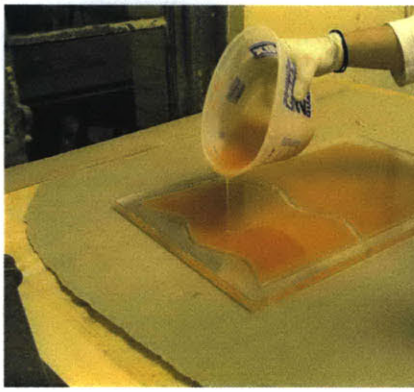






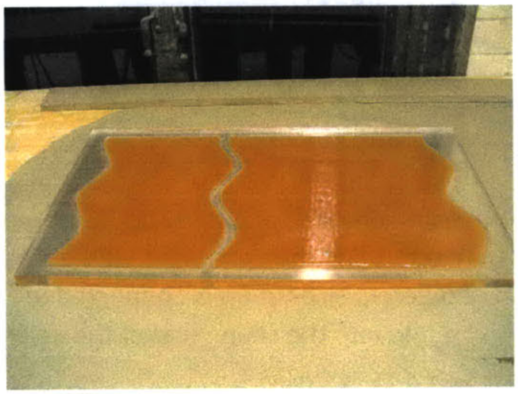


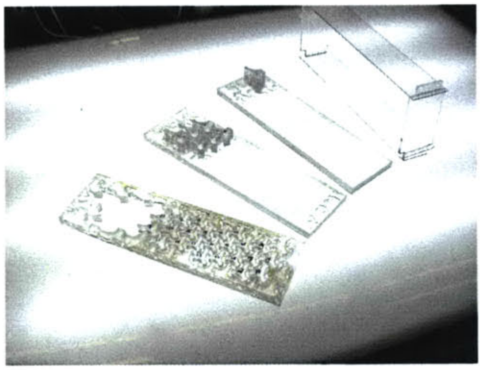


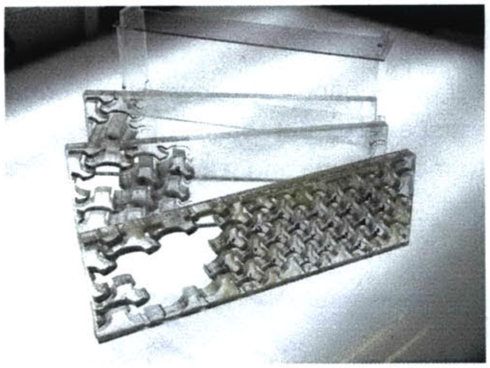


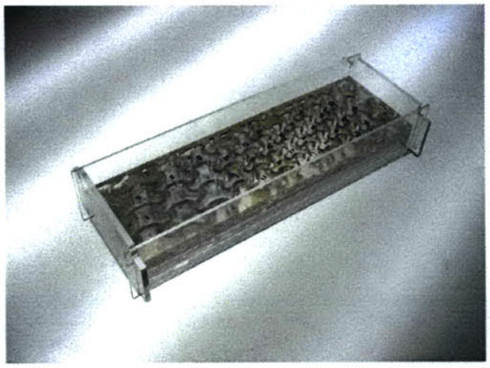
Poured Shape

This proposal explores many aspects related to molding / casting technique. Polyurethane rubber is mixed with luminescent powder, and poured at slow speed. Since this is the very first experiment that involves casting process, parameters such as flow rate, mold design and releasing strength were important aspects to be determined.

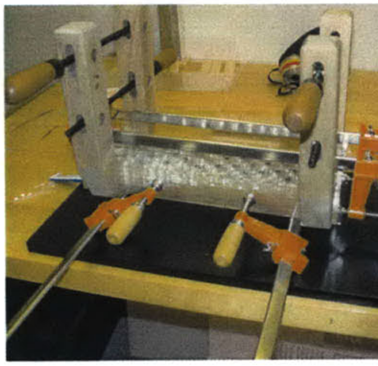






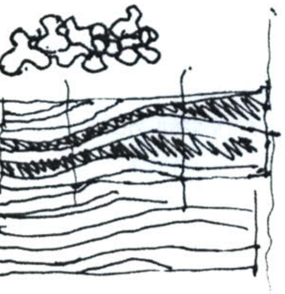


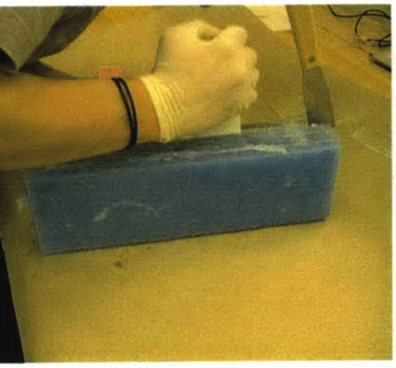
Complex pattern and mold design

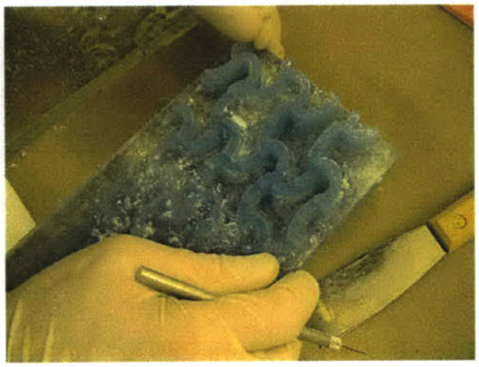


The desire to create 3 dimensionally complex patterns is the primary incentive for this proposal. From FormZ, a 2 dimensional tessellated pattern is generated, and then extruded with each unit at a different height. The goal is to create repetition of different sizes of units connected to form a complex network of channels. Rubber is then poured into the channel after the assembly of the mold.

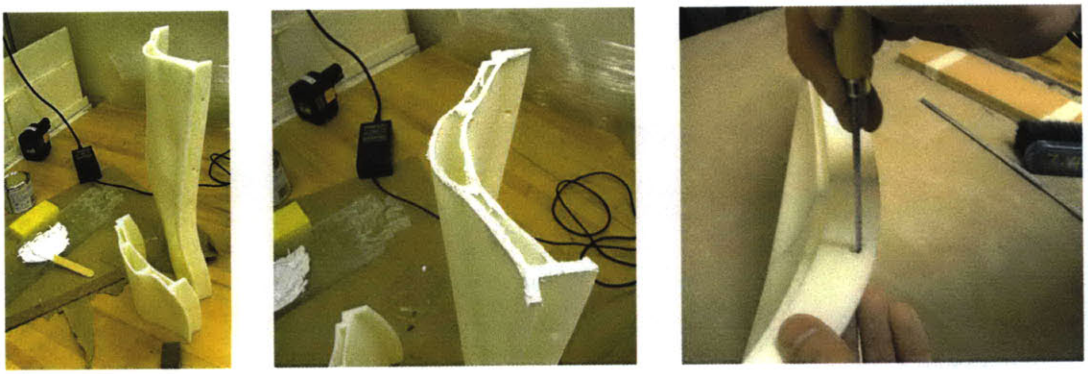
Building on the experience from previous "poured shape" experiment, a detachable multi-component mold is designed from slicing the computer model. The original intention of building the mold is to be able to separate the cast shape easier. However, when the material was ready to be taken out after curing, because of the gaps between each strata of the mold, some material had penetrated. This condition formed a very strong bond between the cast and the mold itself, and after many trials, the material was left attached to the mold.





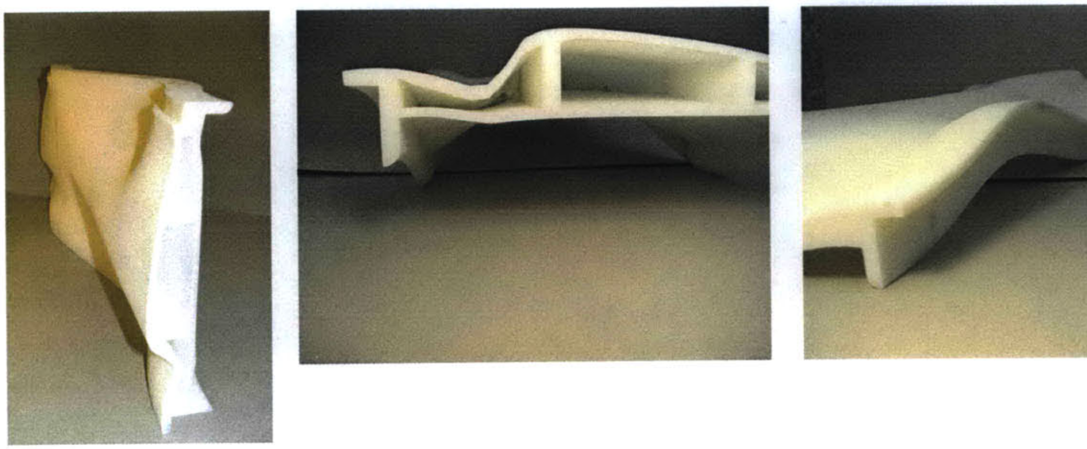


The implication of this condition is valuable; because of this unexpected result, inherent mechanical properties of the material lead to the developments in the next design proposal where the material is partly used as a laminator.



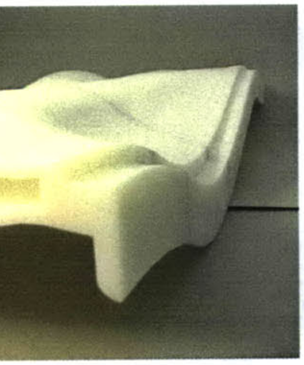
Panel system and mass production

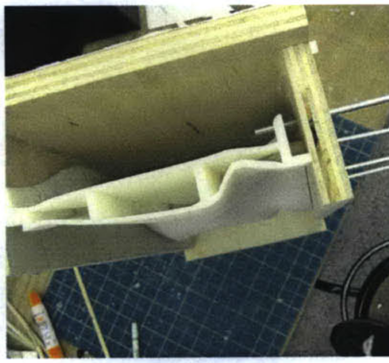
This experiment is based on the design of
dimensionally curved panel system. Prot
with stereo lithography (3D printer) techn
is the main focus of exploration. In additi
methods to general a master mold for pro
repeated units are investigated.



ne interest in mimicking the form of natural phenom-
the design of this panel is based on the gradual slope
d dunes. Similar to the process of the earlier experi-
which based itself on the sine wave of water ripple,
m of this panel was crated using Non-Uniform Rational
nes, or NURBS, in FormZ.

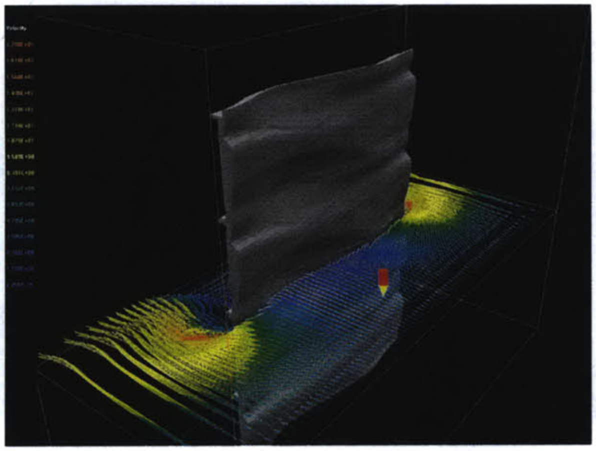
The panel breaks down into three smaller pieces with fittings for mechanical connections on the side. The original intention was to produce multiple units for the purpose of a building surfacing system; however, since this form and its tectonic are based on a stylistic design, and do not really address the unique mechanical and physical properties of the elastmeric material used, therefore this proposal was abandoned.

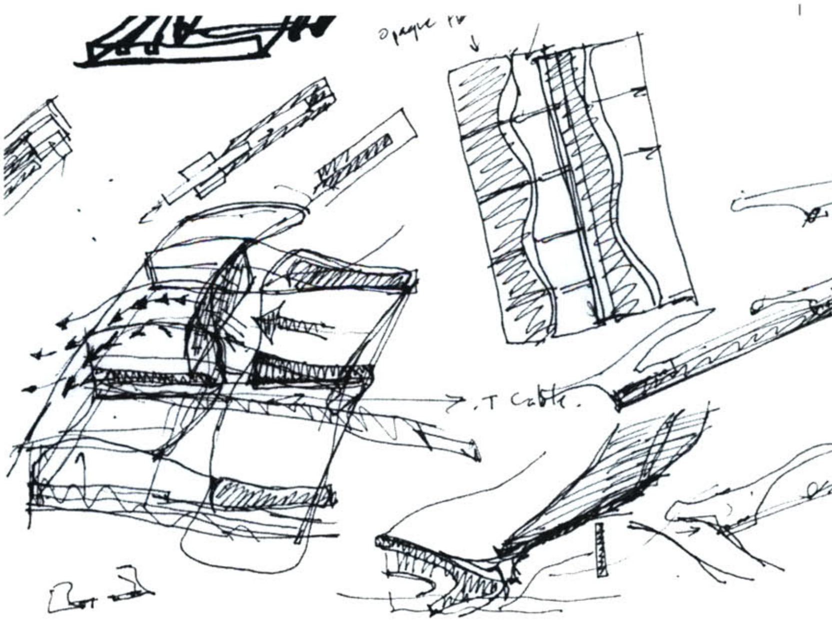




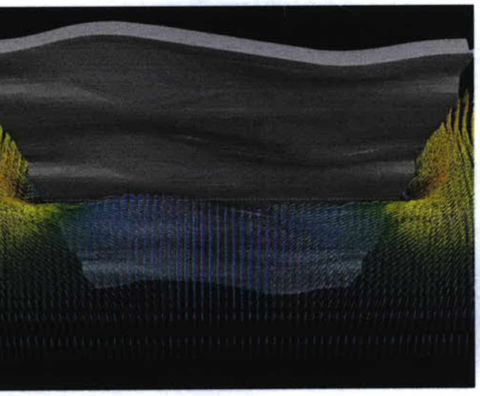
Computational analysis

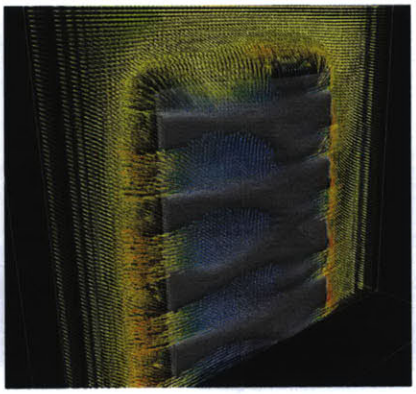
During the design process, with the aid of computational fluid dynamics (CFD) software, the designer can more efficiently identify physical conditions such as temperature, wind speed, flow rate of liquid ... etc. Although the panel system proposal was abandoned, it is important to mention the use of CFD during the design and development.

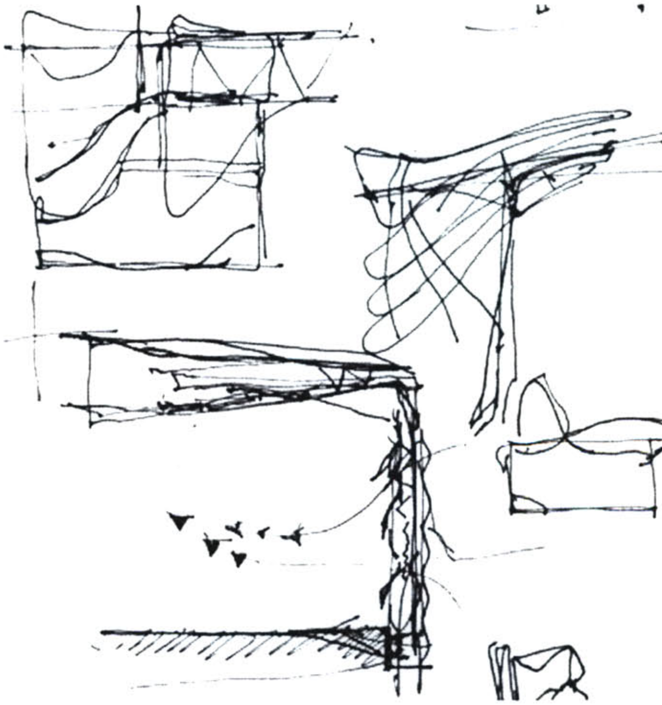


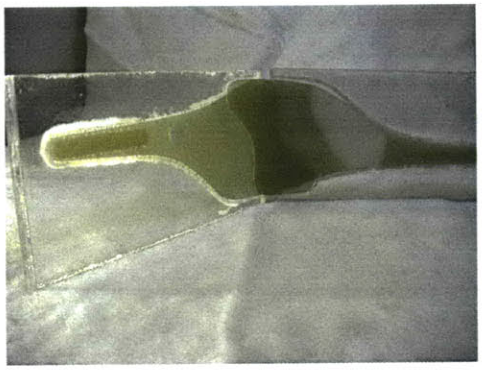


order to examine the interaction with wind, CFD analysis was onducted to determine appropriate methods to introduce diffuse r through the undulating surface of the panel. The result was be used to derive locations and size of openings needed for pecific flow rate and wind speed. Further interpretation of the esult supports that the undulated topography of the surface does elp to slow down prevailing wind, and can be a possible solution r channelling air in high elevation of skyscrapers.



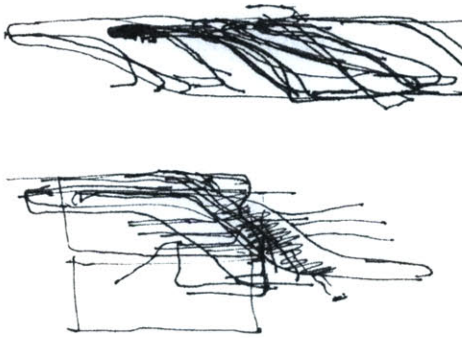


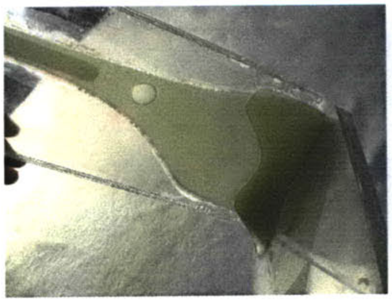


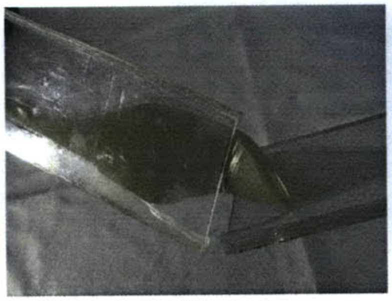


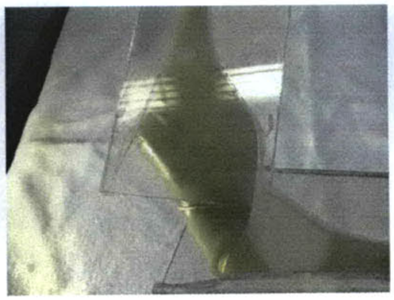
Key joint

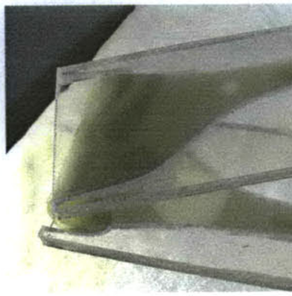
This proposal is the first attempt to join different components by using the material and its unique properties. From rethinking about previous experiments in which the material behaves under many different configuration, to the idea of the transformation from liquid to solid state of the curing process, an interlocking joint is developed.



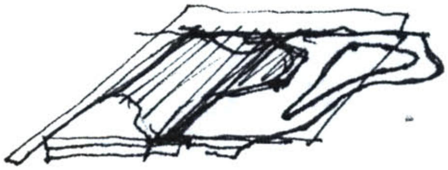


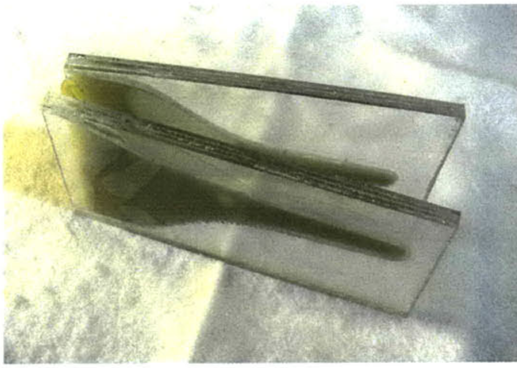


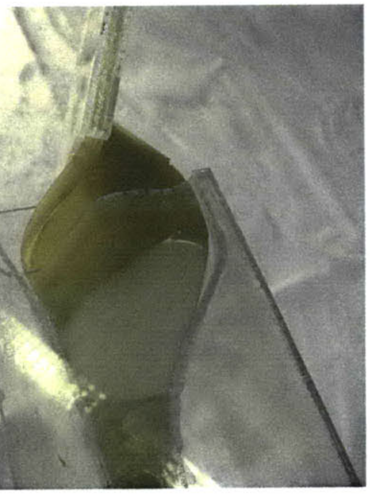


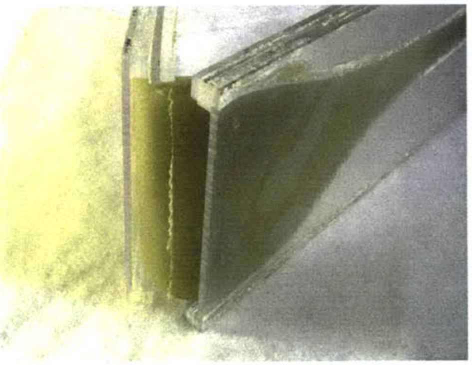


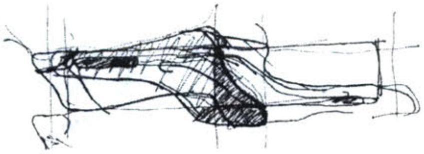
is design, the rubber serves two important func-
s: 1) laminating and stabilizing the two parts,
ovide flexibility in between. Because its
hanical property and shape memory, the joint
vs the two planes to rotate in all x, y, z-axis. The
is also stretchable and will return to its original
tion.

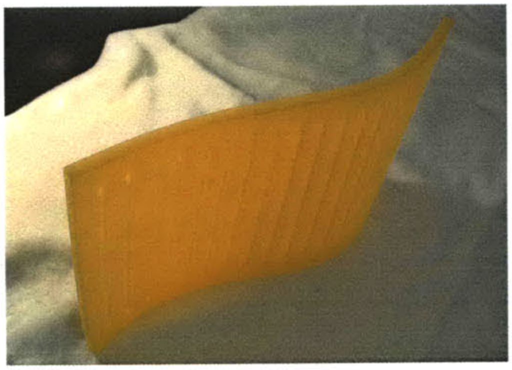








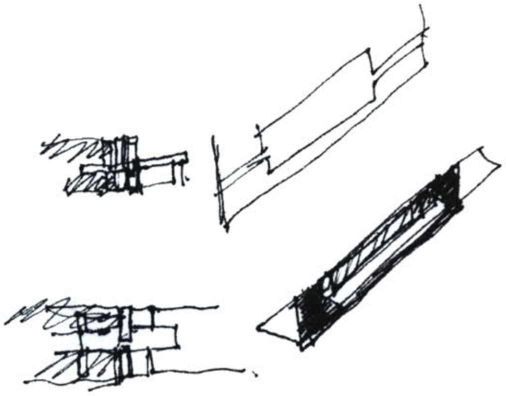


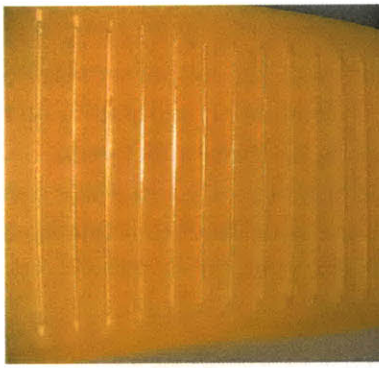


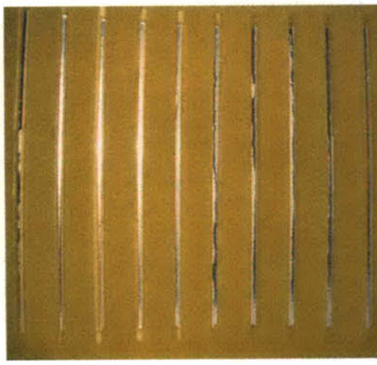
Embedded elements study

In this experiment, plexi-glass strips are intentionally left within a sheet of rubber. The combination of the two creates an interesting composite where light penetrates through at different intensity.

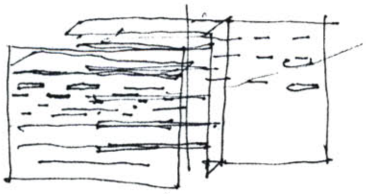
In order to embed elements during curing, the mold needs to be design with a different notion. The role of the mold is expanded, it needs to serve as a shape constraining element as well as a system whose parts can be detached and left within the cast.





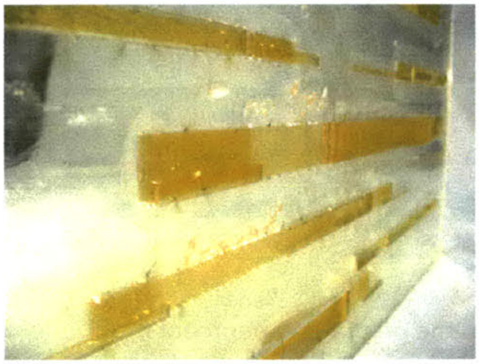


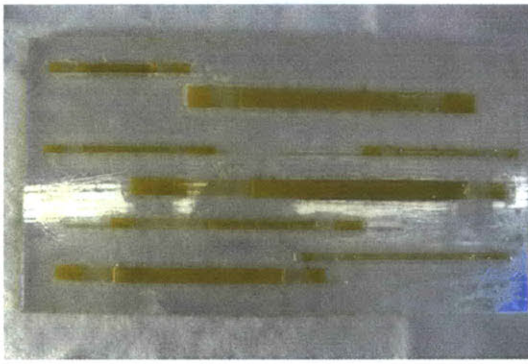
ching band study

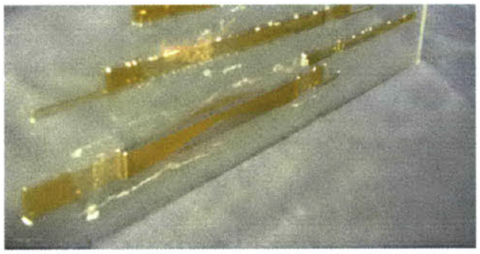


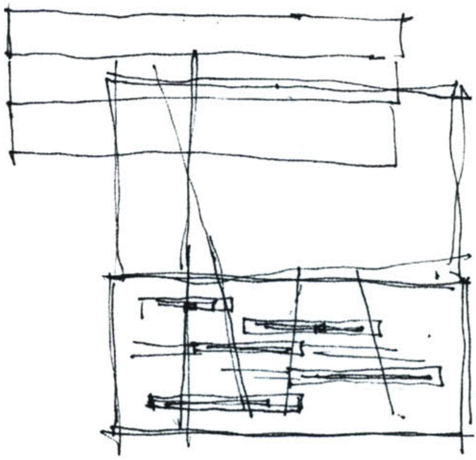
ar the "key joint" experiment, in this study, the
is left completely from the beginning to the
ed product. Rubber is poured into rectangu-
rip openings with different sectional shapes.

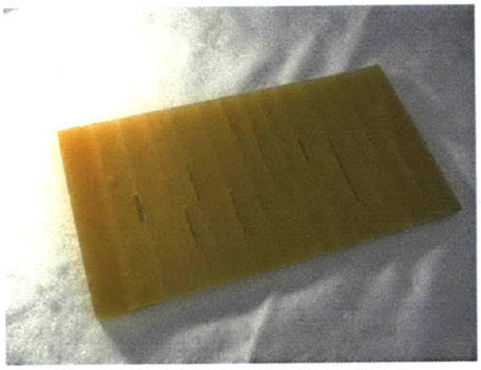
curing, the rubber is locked by the sections,
ntegrated into the planar vocabulary. Parts of
ubber can be deformed to form openings. Fur-
nore, because of its stretching property, exter-
lements can be held against the surface.

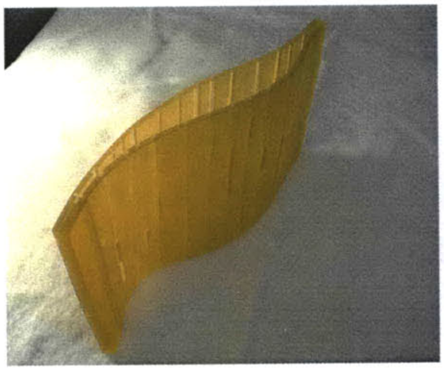


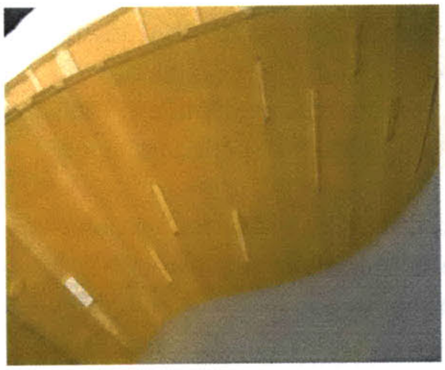






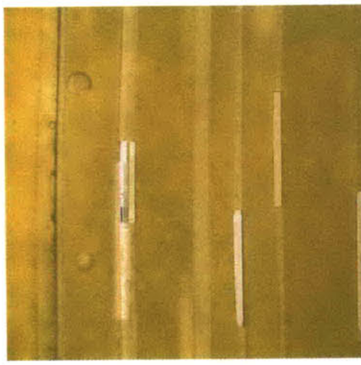


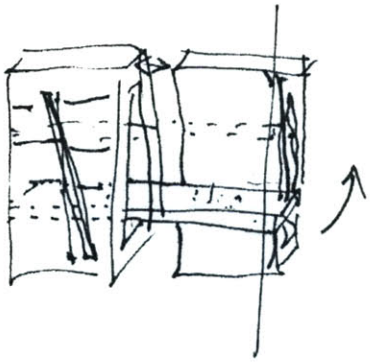


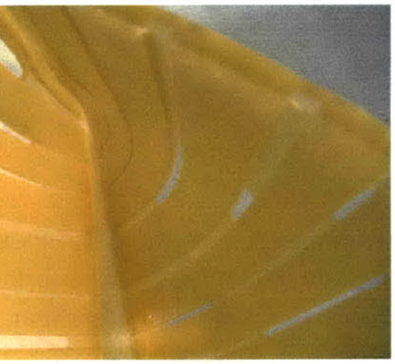


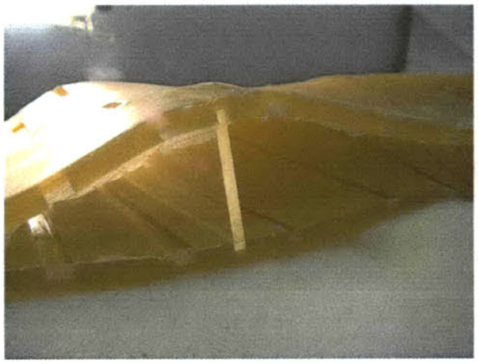
Stretching membrane

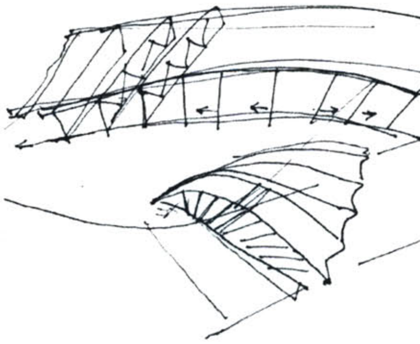
Combining many concepts from the previous experiments, rubber is used in this proposal as membrane for secondary structural members. Grooves and slots are formed on the internal side of a rubber band like skin. The main purpose of these elements is to stabilize the members of vertical rigid structure. Because of the stretching property and flexibility of rubber, vertical members can be held in place with minimal amount of adhesive and no mechanical connection. These indentations also filters illumination from one side. The photo on the right illustrate the quality of how light penetrates through different depths of channels.

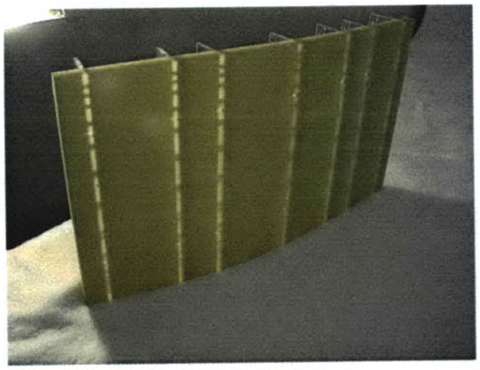


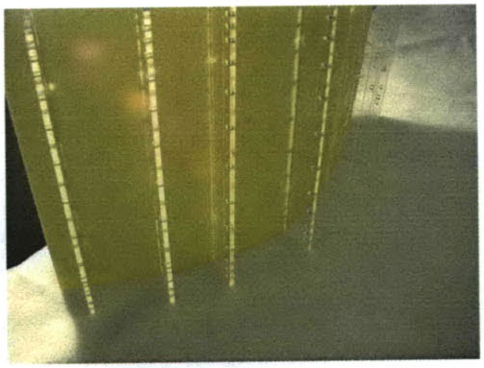


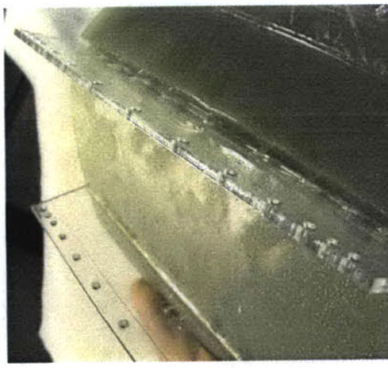








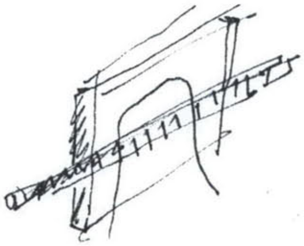


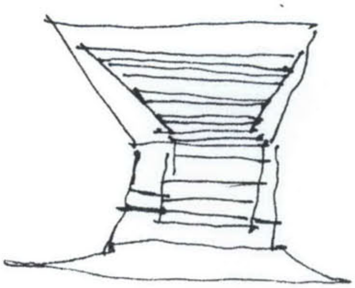


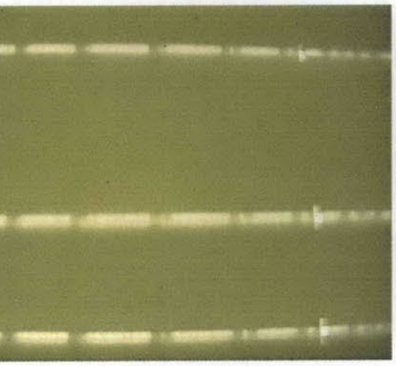
Embedding structural members

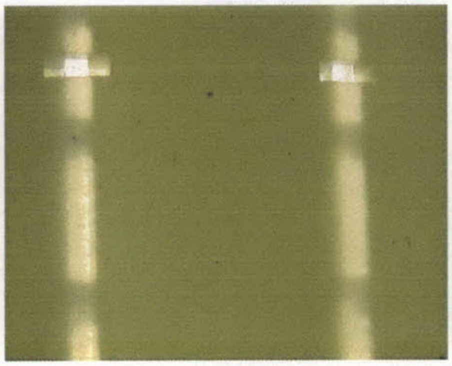
This experiment is a further development of the "embedded elements study". Ple
strips with holes on two edges are embedded as structural members for the surfa
formed by rubber. The goal of this design is to create a free standing system that
addresses the notion of tectonics in an innovative way.

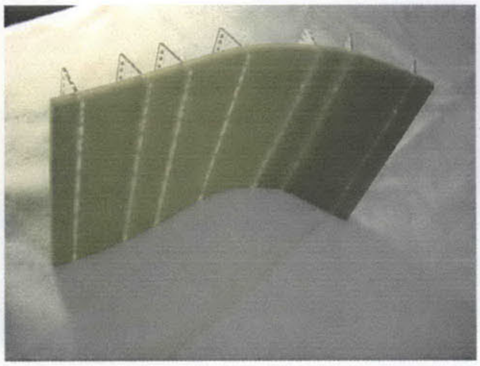
When light filters through the translucent surface of rubber, one begins to see th
that two materials are connected. The small openings where light penetration in
are formed by mold elements holding up vertical members during construction.
condition is similar to holes created on the surface of precast concrete.

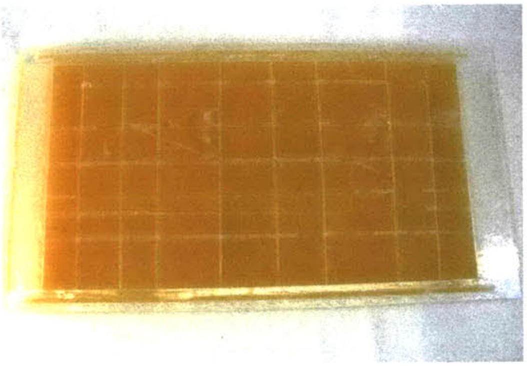


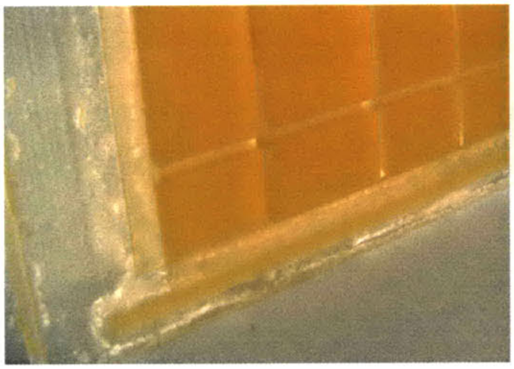






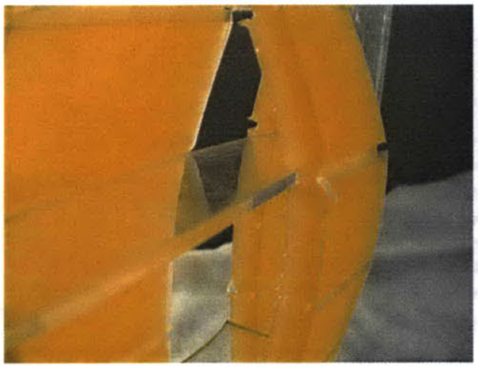


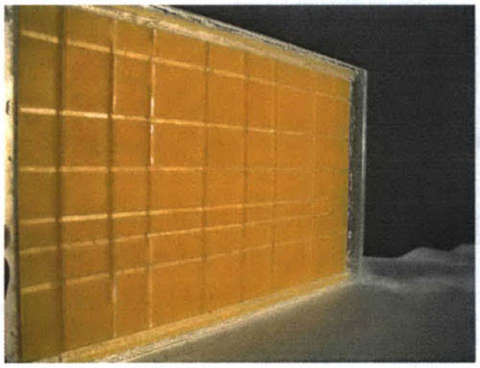


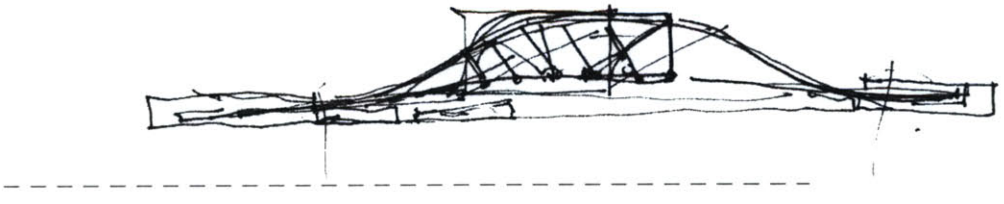


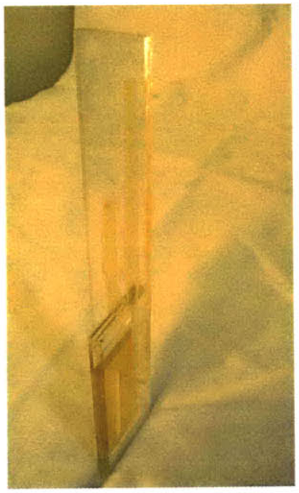
Stretched openings

Similar to the configuration in "stretched membrane", strips of rubber hav
indentations to hold horizontal rigids in place. The strips are planar at cl
position, and can be formed into a variety of shapes depending on differ
combinations of horizontal members in between. In application, the hor
can be used for shelving purpose when applying this technique in a wall



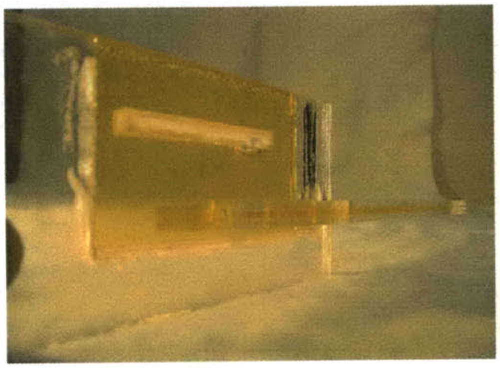


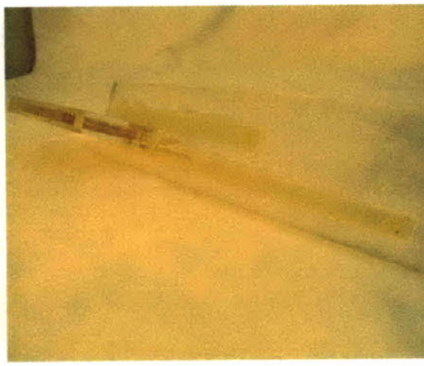


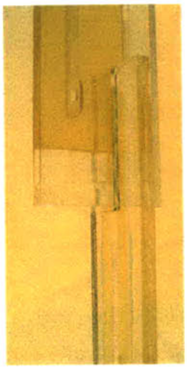


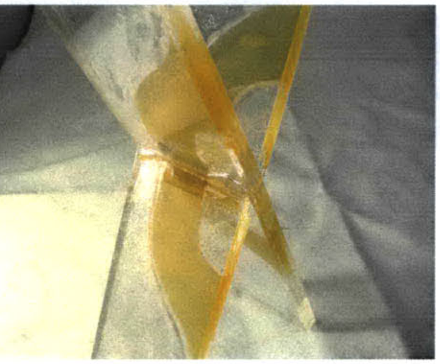
Vertical to horizontal

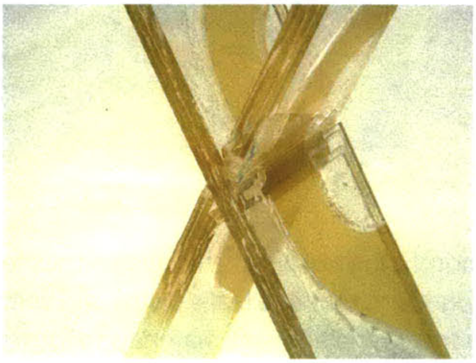
The desire to create a moment of transformation from a vertical to a horizontal plane drives the development of this experiment. Laminated plexi-glass sheets with cavities are connected after rubber fills in and cures. This rubber in this joint technique offers strong lamination property as well as shock absorption. When movements between the two planes fluctuate, rubber behaves like an expansion joint which absorbs part of the stress.

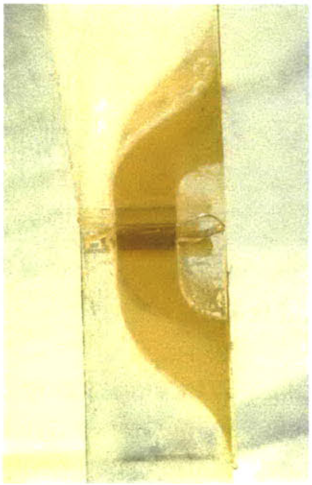


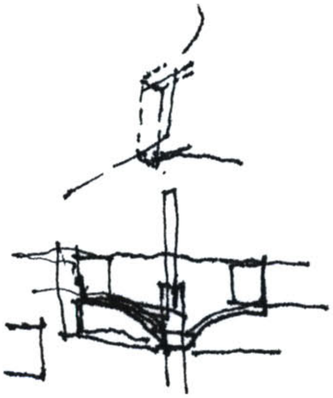






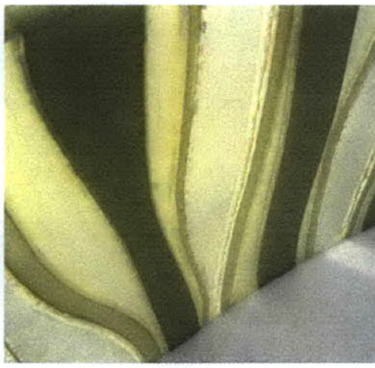






Interlocking planes

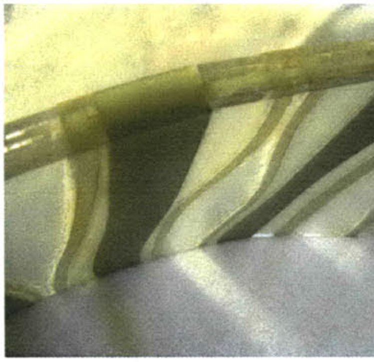
Rubber is used again in this experiment as a laminator and a expansion joint. The X shape from by the two planes has cavity similar to the previous design proposal. An interesting fact is that during de-molding process, one of the plexi-glass member broke while the rubber helped to keep the piece intact. This implies that the function of rubber can also be argue to prevent catastrophic failure in structures.

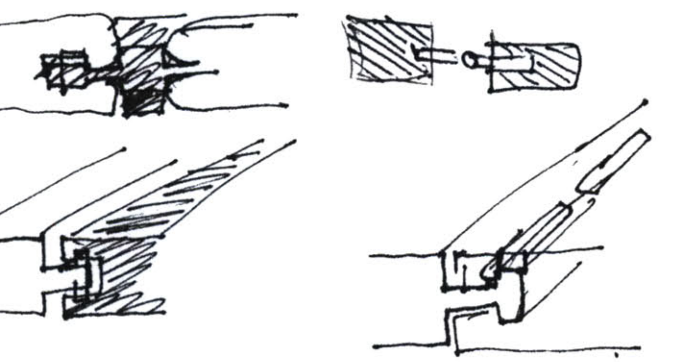


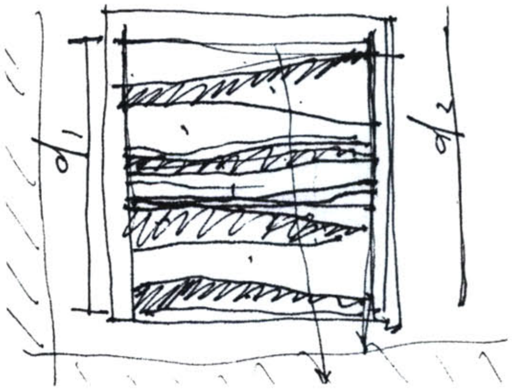
Rigid to soft

Inspired by looking closely at the morphology of a leaf, this design tries to develop an integrated system analogous to that of a leaf's stems and veins. The goal of this experiment is to connect rigid and soft materials to form a flexible surface.

Rubber is poured in between laminated plexi-glass members which has gaps that allows the liquid rubber to flow in. The detail at the edges of rigid members lock the rubber after curing. Variations of curvilinear slits prevent displacements between the rigid and soft parts.



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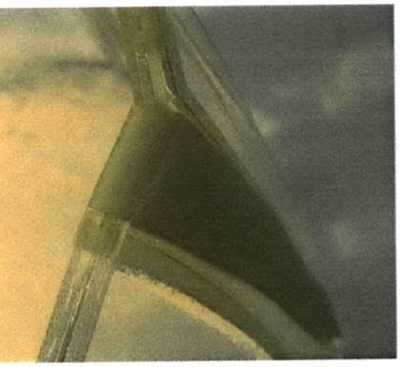
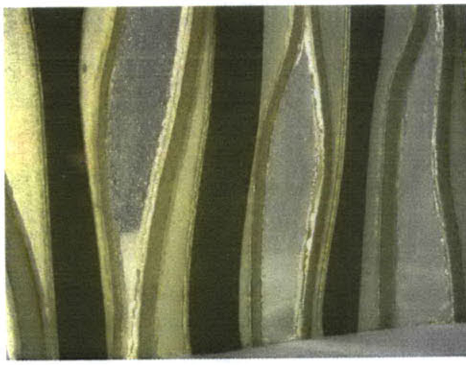
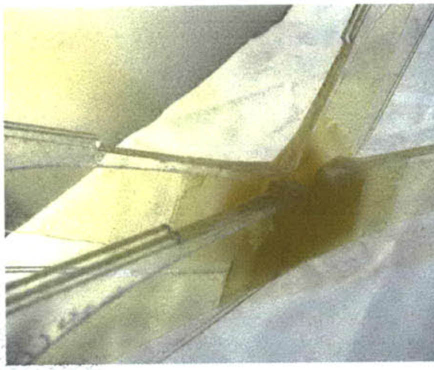


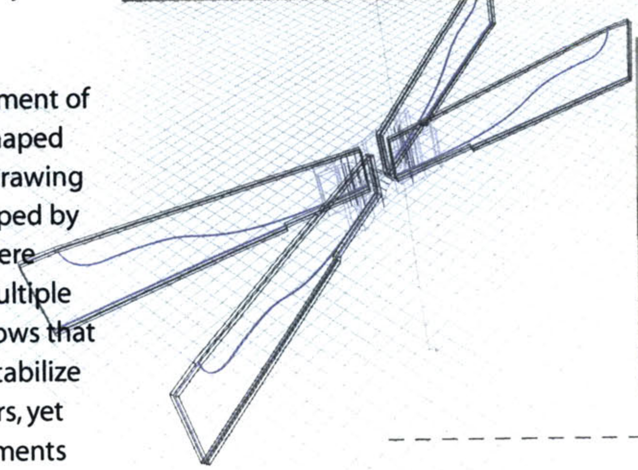


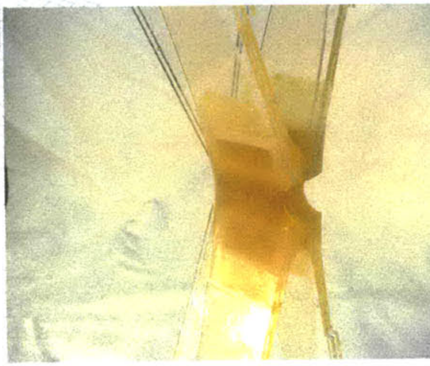
Maximizing flexibility

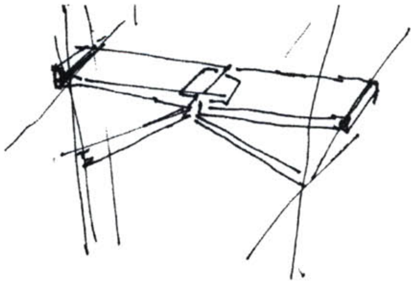
Joints in organic elements are often ones with the most flexibility. For example, cartilage between the bones in human body has the capability to rotate and move in many directions. The rubber investigated in this thesis has properties, such as stretching, flexing and shape memory, that are comparable to functions offered by the properties of organic joining material.

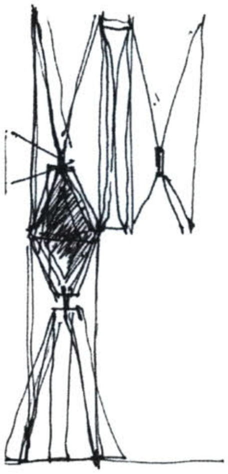
In the last design experiment of this thesis, a flexible X shaped structure is proposed. Drawing from techniques developed by previous experiments, here again, Rubber serves multiple functions. The result shows that rubber can be used to stabilize the connecting members, yet allow freedom of movements between them.

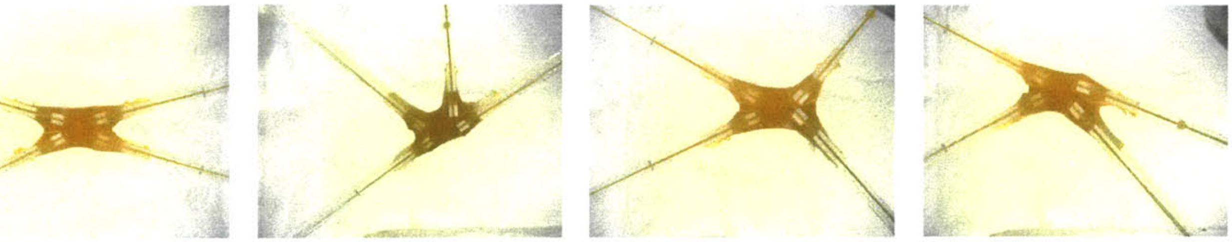


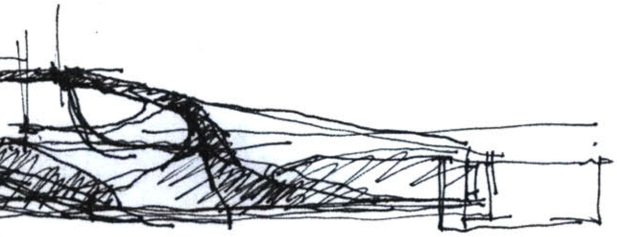


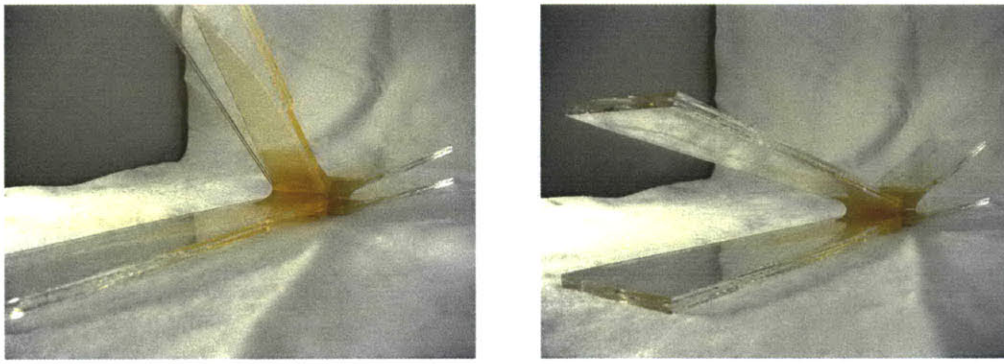








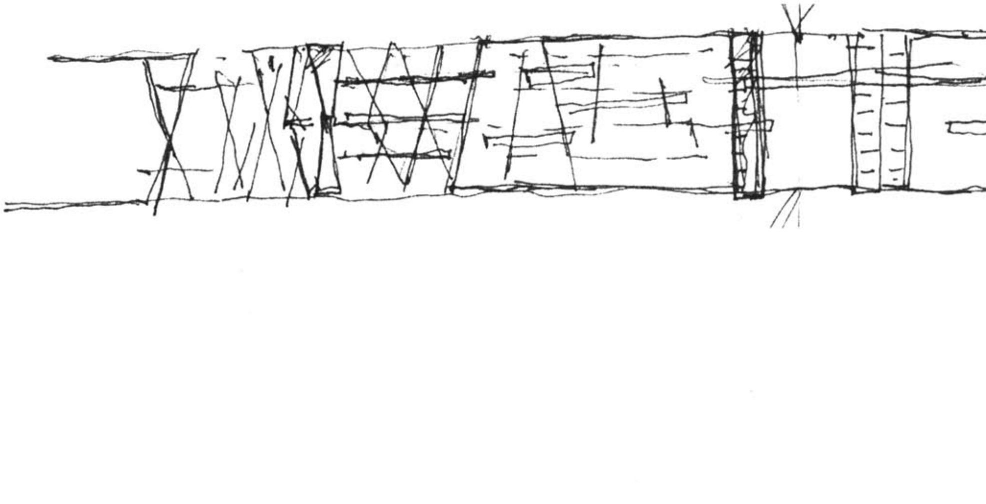


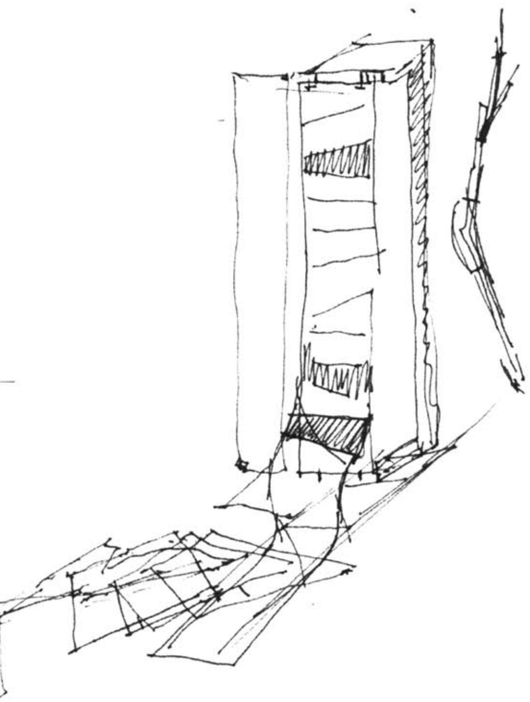


The research and experiment processes should be considere
the most important aspect of this thesis. Regardless of the r
from each design proposal, the most valuable experience is t
unique learning process of the material and its inherent prop
through the notion of discovery. While contemporary mater
fabrication techniques offer designers a great realm of inven
possibilities in architecture, it is important to enter this territ
with sufficient knowledge of each.

Design intent is grounded on realization of intensive knowle
tool and material. As drawings, renderings and models are i
tant elements to represent ideas in design proposal, the phy
substance and means of fabrications are vital to the materia
of architecture. This thesis advocates that investigations int
tific, technical and fabricating aspects are important founda
reaching the definition of a tectonic case for synthetic rubb

conclusion





Although this thesis contrasts design studio projects by having neither site nor program, it does respect the significance of these criteria in architecture. Instead of looking at multiple scales of forces, this research focuses on the detail level of joints and material. The domain of investigation is inspired by Frampton's argument that the joint is "the nexus around which the building comes into being and is articulated as a presence." In order to be more focus on this aspect, the thesis concentrates in depth on the materials and techniques through design experiments.

In retro perspective, some design proposals of this project would have been inconceivable without the knowledge accumulated from interactions with the physical substance. For example, from the making of "complex pattern and mold design", the unpredicted difficulty to remove the mold has inspired further development in the "key joint" experiment. The material starts to serve multiple functions both as joint and laminator. It is also from that moment, the research shifts focus from making representational form, to contemplating inventive construction with the unique properties of the material.

From the experiment results, potential applications can be further engineered. Integrating polymeric material into complex building assemblies has hypothetic potential to prevent catastrophic structure failure. In addition, elastomeric materials have the capability to yield greater flexibility in joint design. Nevertheless, to safely and more efficiently implement the material into real scenarios, technical based laboratory testing is an absolute necessity.

The framework of this thesis offers architects to initiate an inventive process of design in a refreshing way. Since the material behaves differently under various mold configurations, specific material tendencies can only be identified from the production process. These factors are beyond the generalized material properties obtained from readings. Rooted within each design experiment, new ideas can be derived from the heightened familiarity of material's tendencies. From this perspective, with respect to other architectural conditions, design intent can be more creatively manifested. It is with this notion to acquire knowledge of the materials; innovative moments start to take place in design problems.

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