Hyper-light Architecture:
Composite Tower for Hong Kong

Jeffrey Tsui

Bachelor of Science in Civil Engineering
Columbia University, New York, NY 1997

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 2001.

[June 2001]

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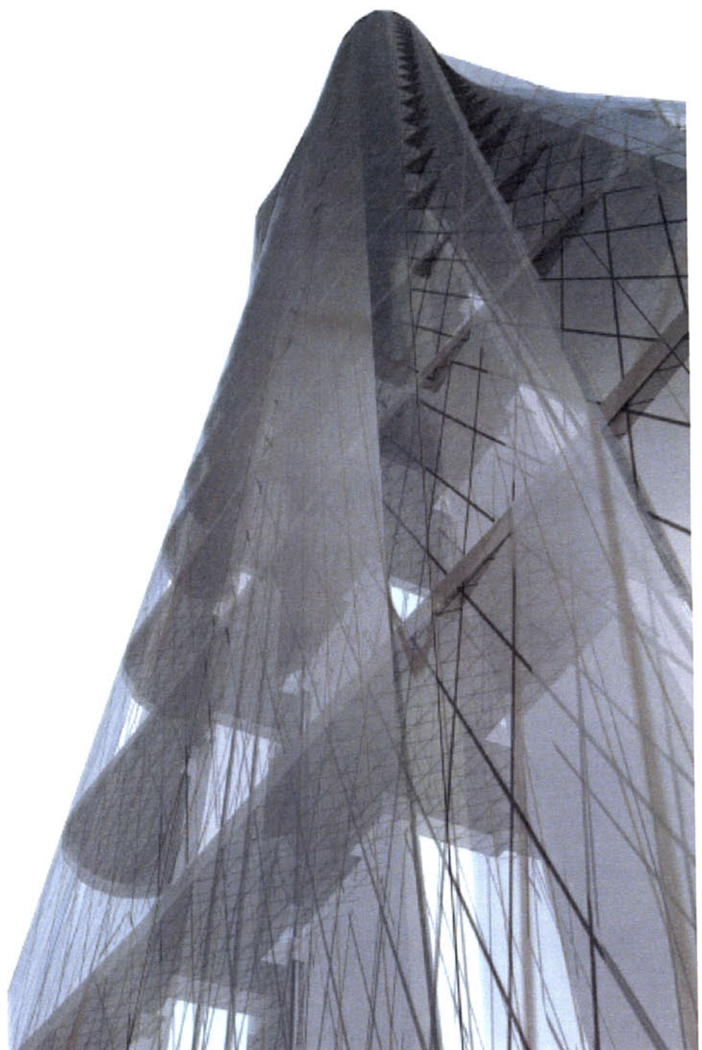
[0.0] cover image

For my parents and sister -

Composite Tower for Hong Kong



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The initial concept of the thesis begins with an interest in understanding the materials, manufacturing and aesthetics of modern product design and its relationship with architecture and space. The approach to the problem begins with an exploration of specific materials that are commonly used in other design and manufacturing fields but that are currently underutilized in the building construction industry.

The thesis is an investigation of exploiting composite materials in developing a structural system for buildings and construction. Specific properties of composites, various connection techniques as well as different construction/fabrication methods involved are essential issues that are explored throughout the design process. The project targets at creating a new typology and aesthetics in vertical building systems that takes advantage of the specific structural characteristics of these materials. Utilizing the characteristics of high-density site conditions such as the Central district in Hong Kong and through an application of a sensible programmatic organization, the project serves as a demonstration of the design within a realistic environment as well as within pragmatic constraints.

The outline of the thesis is as follows:
1. Research and investigation of materials
2. Site analysis and background information
3. Design requirements, criteria and decision-making
4. Models for experimentation and illustration of design ideas
5. Presentation materials

thesis supervisor:
Peter Testa
Associate Professor of Architecture, MIT

contents

acknowlegdements

I would like to thank my advisor Peter Testa and Devyn Weiser, who have guided me through the three and a half years of architecture at MIT. Your teachings and advices have prepared me well for all kinds of future career paths.

To my committee:
Thank you for all your perceptions and various kinds of expertise through each step of the project. It would not have come such a long way without your constant supports and encouragements.

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Edwin and Joe – for helping me out so much in the last couple of days of production, and also setting up the final presentation

Manin – for climbing up the ladder and hanging up the top panels at the AVT

Larry from *www.carb.com* and *www.strongwell.com* - for sending me really nice free samples

[1.0]

[introduction]

[background]

[case studies]

[1.1]

[1.3]

"Architecture is the will of the present time expressed in space. Living. Changing. New."

- Mies van der Rohe, July 1923

[1.2]

introduction

Although the Guggenheim Museum in Bilbao is developed by Frank O. Gehry's office using CATIA, the aerospace computer modeling program, the office constructed the museum the way Gustav Eiffel constructed the Statue of Liberty, cladding its complex skeletal frame with a shiny sexy skin. Appealing as an architectural form, the museum is, in a way, a very unfortunate example that illustrates the fact that the space-age computer design process fell back on a highly laborious means of construction that has not evolved much conceptually since the late 19th century.

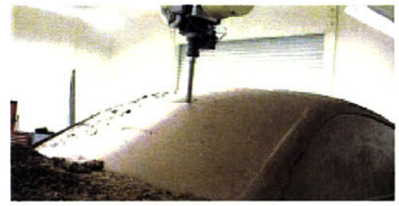
[1.4] Gehry's Guggenheim in Bilbao

Architects, Gehry among others, are conceiving their buildings on screen, often with animation programs that encourage curviplanar forms. They have arrived at a place of architectural design between materials, where the old materials and construction methods are strained, if not actually obsolete, and the new ones have yet to appear. Charles and Ray Eames reached the limits of bending plywood, and embarked on a search of a more cooperative, industrially practicable material. In the early 1950's, fiberglass finally allowed Eames to realize the doubly curved monocoque form that Charles had conceived with Eero Saarinen more than a decade earlier. Whether the vision is produced by hand physically or on screen virtually, the upcoming generation of young architects is struggling with the issue of buildability of complex forms. While some of these architects are trying to bring their cyber visions into real space by adapting new fabrication techniques with existing materials, others, being more ambitious, have been searching for the "divine material" and the dream of making it work. This thesis project is an exploration of the latter approach.

[1.5] Karim Rashid's Garbo, is in itself a monocoque structure where its continuous "skin" also serves as supporting extra loads.

Unprecedent advances in both computer and manufacturing technologies - a phenomenon often called "technology transfer" - mean architects may now borrow the tools and techniques of seemingly unrelated industries, from industrial design to automotive and aerospace engineering to computer game and film industry technology, and apply them to their own trade. For example, utilizing the computer-aided prototyping technology available nowadays, the digital design process can be incorporated into the construction/manufacturing methodology seamlessly. This method of mass-customization provides an opportunity for implementation into building construction in any metropolitan cities worldwide, where issues of efficiency and convenience are critical.

One example of technology transfer involves the automobile industry. A high technology design and development organization, Ctek (Creative Technologies) who specializes in creating and reproducing contoured components, utilizes a CNC (computer numerical control) 5-axis milling machine to create clay models in the size of a full-scale car. One can also imagine building components be manufacured in a similar way.



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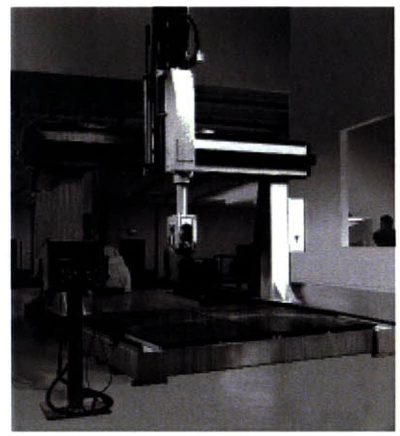

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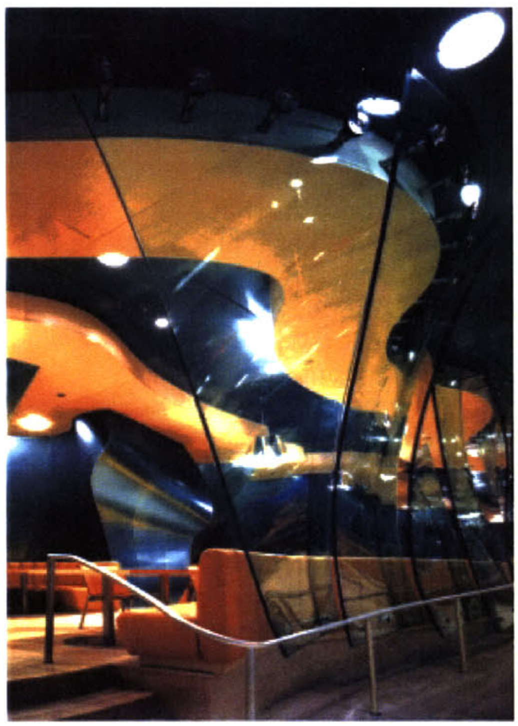
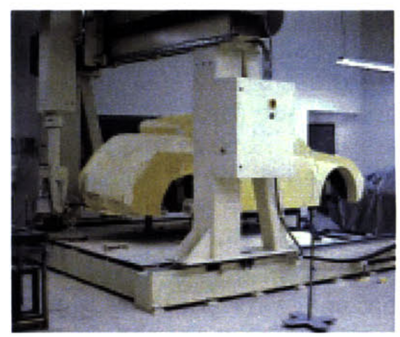
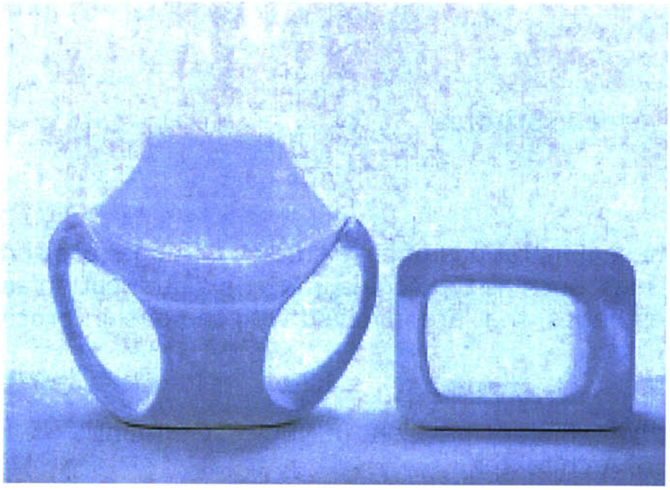


[1.8] C-tek also built the compound-curved glass panels in Gehry's Conde Nast project in New York.



[1.9] C-tek's CNC 5-axis milling machine produces full-scale car models.

Since the initial interest of the thesis revolves around the aesthetics, materiality and fabrication of modern product design, the exploration of architecture begins with an examination of the characteristics of composites: strengths and weaknesses. The form of architecture here is about providing an energy-sensitive environment within an efficient structural system, at the same time maximizing usable and flexible floor area in a high-density urban context. The unique appearance of the building is designed to takes full advantage of the strengths of the materials; a similar form would be difficult or expensive to achieve when using other conventional materials.



[1.10] Richard Dewhurst and Proportion's organic 'The Shell Series' is made with fiberglass.

The project aims at providing a mixed-use environment for our lifestyle that constantly demands adaptability and efficiency in the Central district of Hong Kong. Issues of flexibility and changing needs are addressed through the spatial organization of the public and private sector of the program. In the public domain, a combination of different programmatic elements, such as retail and recreational spaces, is included, while in the private domain, a modern typology of housing, hotel and workspace prototypes is incorporated.

background

The architectural philosophy of the Bauhaus and Walter Gropius in the 19th century changed the way people at the time thought of building and construction. It is more efficient to build with the method of mass-production of parts that can be assembled on site. There is no doubt that the Industrial Revolution facilitated this idea into reality, but the Industrial Revolution also had an impact on the aesthetics of architecture that was produced: it made architecture look like machines. With computer-aided design and manufacturing technology, similar idea could be implemented more efficiently with a new sense of aesthetics. Industrial design, for example, has utilized much of the CAD/CAM technologies in its design and manufacturing and has created objects that are organic and seamless. Modern architectural design and detailing, for instance, could also benefit from these technological advances.

[1.11] Bauhaus workshop: metal, fabric, wood and glass

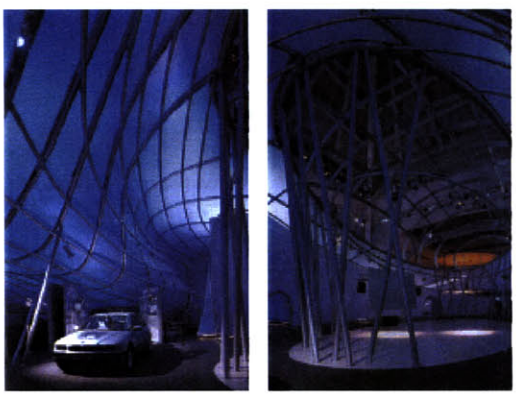
The project of this thesis will take place in the downtown district of a metropolitan city, Hong Kong, even though the project could have significant implications on downtown areas of other metropolitan cities such as Tokyo, London, or New York. Because of their inherit characteristics, such as high land value, pollution, traffic conditions and fast-paced human activities, these cities require very careful manipulations of spaces in the design of the architecture. As a result, the choice of material, the method of construction, and the organization of spaces are the main focuses throughout the design process of the thesis project.

case studies

These illustrations of case studies demonstrate some of the issues, such as typologies, materials, fabrication and aesthetics, that are involved with the design process of the project.

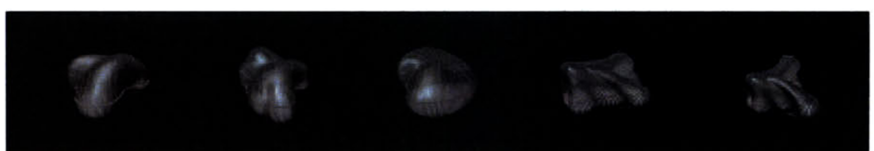
BMW exhibition pavilions in Munich, Germany
ABB Architekten

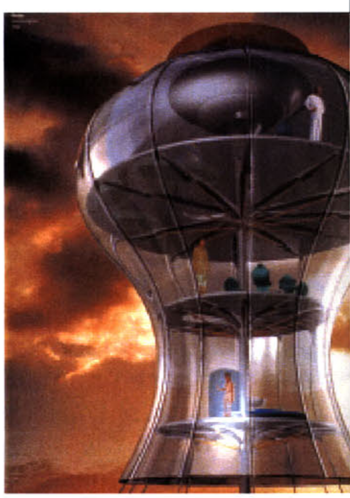
Embryonic houses.
architect: Greg Lynn



[1.12] BMW Paviliion in the Hannover Expo 2000

[1.13] Greg Lynn's Embryonic houses





[1.14] Lovegrove's Solar seed

Solar seed
designer: Ross Lovegrove

Torten Housing Development, Dassau.
architect: Walter Gropius.

Suspended Tower.
architect: B. Fuller.

[1.15] Starck's Asahi Super Dry Hall

[1.16] Ikon Tower by Kovac Malone Architects

[1.17] Gehry's Vitra architectural complex

Asahi Super Dry Hall, Tokyo.
architect: Philip Starck.

Guggenheim Museum Bilbao.
architect: Frank O. Gehry.

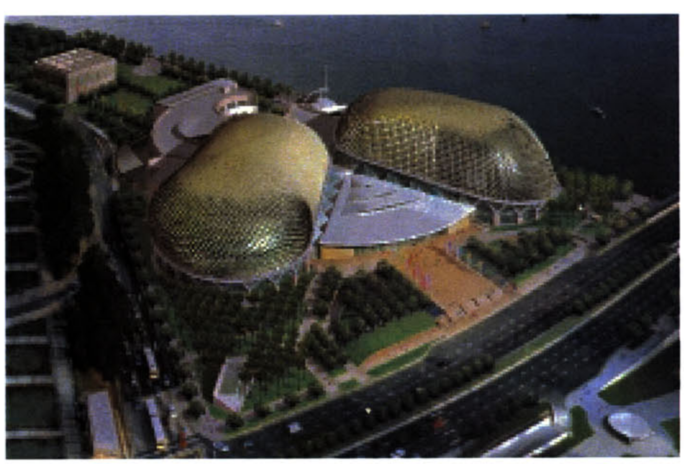
Austrian Cultural Institutte.
architect: Raimund Abraham.

The Ikon Tower, Melbourne, Australia.
architect: Kovac/Malone architects

The Esplanade: Singapore Performing Arts Center
architect: Michael Wilford

[1.18] Gehry's Vitra Design Museum

[1.19] Gehry's Vitra Center



[1.20] The Esplanade: Theaters on the Bay in Singapore by Michael Wilford

LVMH Tower, New York.
architect: Christian de Portzamparc.

Bank of International Settlement Extension Project, Basle, Switzerland.
architect: Toyo Ito

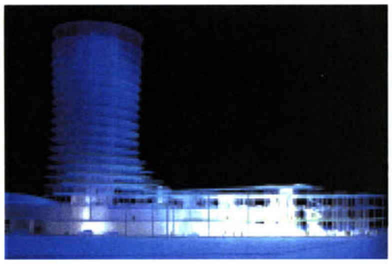
Silver Hut. Tokyo 1984
architect: Toyo Ito

Singapore Performance Arts Center, Singapore.
architect: Michael Wilford

Vitra furniture museum and factory, Weil am Rhein, Germany.
architect: Frank O. Gehry.

Vitra international headquarters, Birsfelden, Switzerland.
architect: Frank O. Gehry.

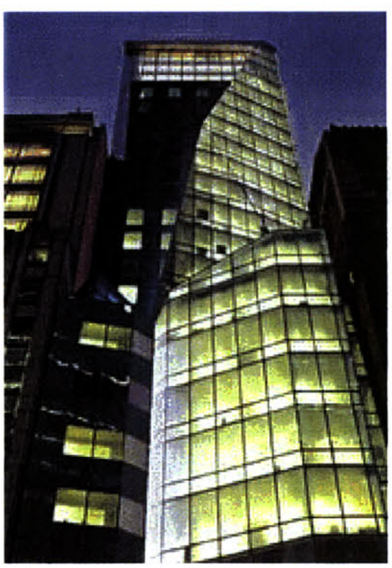
Vitra fire station, Weil Am Rhein, Germany.
architect: Zaha Hadid.

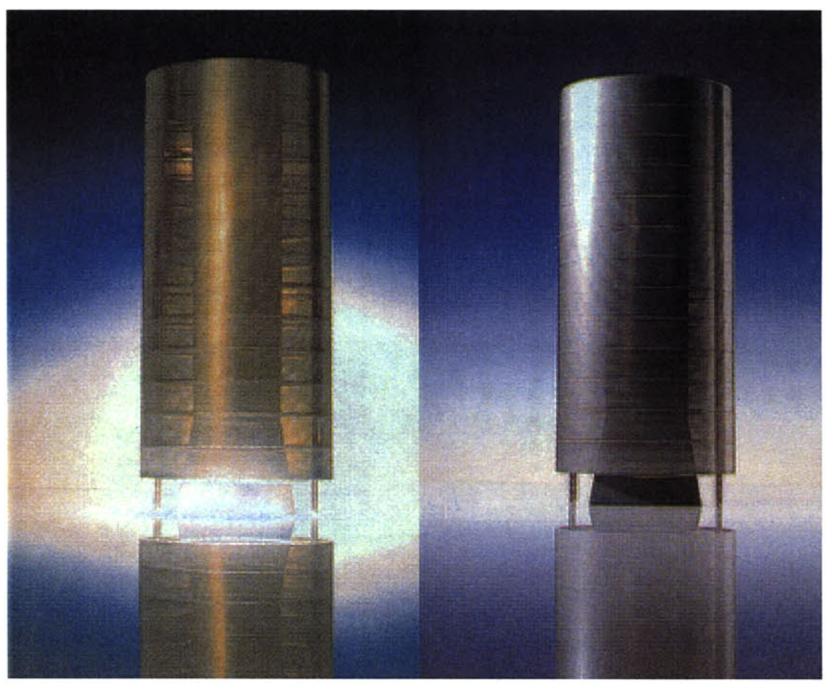


[1.21] Toyo Ito's Bank competition in Switzerland

[1.22] Zaha Hadid's Fire Station

[1.23] LVMH Tower in New York





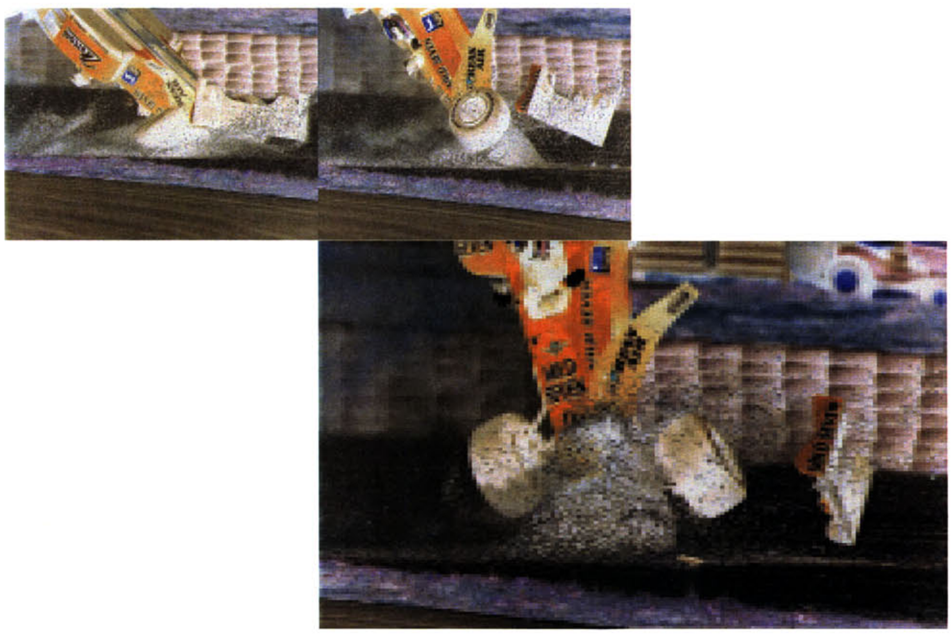
[1.24] Toyo Ito's Silver Hut

[2.0]

[composites]

[fabrication]

[applications]



[2.1]

"When a driver walks away from a crash like this, he can thank the high strength, lightweight carbon fiber composite that forms his cocoon."

composites

The term *composite* refers to a homogeneous material made up of two individual components whose combined physical strength exceeds the properties of either of them individually.

Different types of composites include:
1. timber/wood composite
2. reinforced concrete
3. fiber-reinforced plastic

One kind of composite that is explored in the thesis is fiber-reinforced plastic (FRP), which consists of a fibrous reinforcing network embedded in the cured resin matrix. The thermosetting type resin is a plastic that cures from a liquid to a solid through a chemical reaction of its two components. Mud and straw is an example of a form of composite; the mud acts as a resin matrix, while straw is the reinforcing fiber. These composite materials are combined and processed by one of a number of methods to meet certain performance and appearance requirements as a finished component or composite. While FRP allows for greater design flexibility previously prohibited by the limitations of traditional building materials, it is also non-corrosive, strong, lightweight, maintenance free, and can be erected efficiently and economically. Per unit weight, FRP is among the strongest commercial materials available. Its strength per weight is stronger than concrete, steel or aluminum. First used in the aerospace industry, fiber-reinforced plastic, especially carbon fiber, is known to be very expensive to manufacture. Concrete and steel, for example, are priced per ton, while carbon fiber is priced per pound.

[2.2]

Other characteristics of FRP products include:

1. non-corrosive, strong, lightweight, maintenance free, and can be erected efficiently and economically
2. lightweight; weigh less than two pounds per square foot of surface area
3. shape can be curved, corrugated, ribbed, or contoured
4. can be produced to be watertight
5. have excellent weatherability, heat resistance, chemical resistance and fire retardant properties
6. have at least a thirty-year life cycle

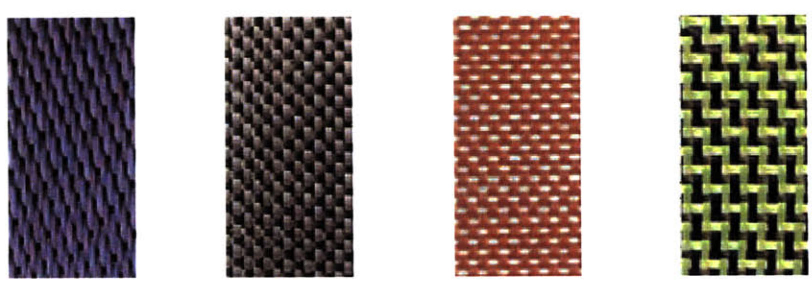
The physical properties of composites are fiber dominant. This means that when resin and fiber are combined, their performance remains most like the individual fiber properties. For example, it is not satisfactory to merely average the tensile strengths of fabric and resin to determine the strength of a panel. Test data shows that the fibrous reinforcement is the component carrying the majority of the load. For this reason, fabric selection is critical when designing composite structures.

The average fabricator has a choice of three types of reinforcing materials with which to construct a material. These are fiberglass, carbon fiber, and Kevlar*. All three have their attributes and short-comings, and are available in numerous forms and styles.

The most widely accepted and least expensive reinforcement is fiberglass. It has been used successfully in many applications since the 1950's, and much is known about its properties. It is relatively lightweight, has moderate tensile and compressive strength, is tolerant of both damage and cyclical loading, and is easy to handle and machine.

Carbon fiber is a modern reinforcement characterized by extremely low weight, high tensile strength, and high stiffness. The material handles easily and can be molded much like fiberglass. However, some advanced techniques are necessary to achieve the maximum properties of this material. Carbon fiber is also the most expensive of the reinforcing fibers. This fact often limits its use to parts needing selective reinforcement or high stiffness with the least weight.

Kevlar, the most common aramid type fiber, offers a third reinforcement option. Kevlar exhibits the lowest density of any fiber reinforcement, high tensile strength for its weight, and superior toughness. It is priced favorably between fiberglass and carbon fiber. Kevlar is puncture and abrasion resistant, making it the reinforcement of choice for canoes, kayaks, and leading edges of airfoils. On the down side, Kevlar is difficult to cut and machine during part fabrication. A pair of sharp scissors should be dedicated solely to



carbon/carbon glass/Kevlar Kevlar/carbon

[2.3] Different fiber reinforcements produces composite with different strengths.

cutting Kevlar. It also has a low service temperature and poor compressive properties. It is possible to combine Kevlar with other materials creating a hybrid laminate to compensate for the shortcomings.

The following is a chart comparing the relative properties of reinforcing fabrics.

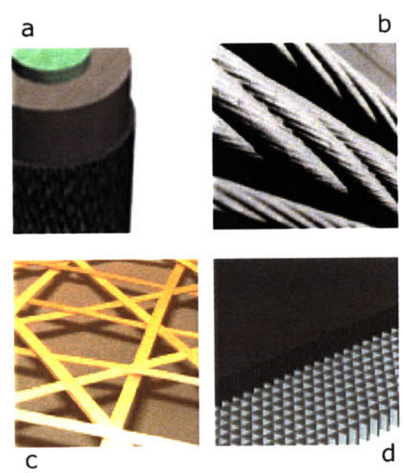
The legend is as follows: P=Poor, F=Fair, G=Good, E=Excellent

	Fiberglass	**Carbon**	Kevlar
Density	P	**E**	E
Tensile Strength	F	**E**	G
Compressive Strength	G	**E**	P
Stiffness	F	**F**	G
Fatigue Resistance	G-E	**G**	E
Abrasion Resistance	F	**F**	E
Sanding / Machining	E	**E**	P
Conductivity	P	**E**	P
Heat Resistance	E	**E**	F
Mositure Resistance	G	**G**	F
Resin Compatibility	E	**E**	F
Cost	E	**P**	F

Metals have for many years regarded as the only materials of construction where maximum mechanical properties are required. However, their capabilities have reached the stage where further marked increase in performance is not likely to be achieved. Since the demands for technological progress, particularly in aircraft and aerospace, are unlikely to be fulfilled by metals alone, a search for alternative types of constructional material has been under way for some time. The concept of using composites containing fibers of exceptional strength or stiffness is not new, but it is only in the last decade or so that suitable materials have become available, and from the chart above, carbon fiber is the most promising.

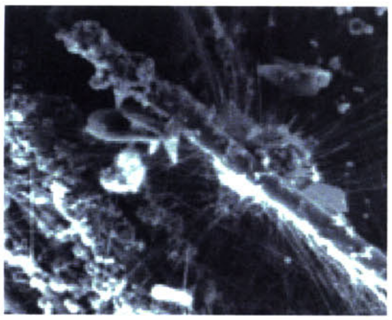
As for this project, the types of composites that are utilized includes the following:

a. composite reinforced and wrapped concrete column
b. carbon fiber woven cables
c. pultruded structural mesh (for skin)
d. composite reinforced concrete slabs



[2.4]

As mentioned earlier, reinforced concrete is also one type of composite. A relatively brittle material, unreinforced Portland cement concrete will crack and fail when subjected to tensile stresses. Since the mid 1800's steel reinforcing has been used to overcome this problem. As a composite system, the reinforcing steel is assumed to carry all tensile loads. When fiber reinforcing is added to the concrete mix, it too can add to the tensile loading capacity of the composite system. In fact, research has shown that the ultimate strength of concrete can be increased as much as 5 times by adding fiber reinforcing. This kind of concrete is refered to as fiber-reinforced concrete, or FRC.



[2.5] A microscopic image of a FRC section shows how relative sizes of fiber and cement. The type of fibers, the volume percent, the orientation and the aspect ratio of the fiber will affect the tensile strength of the reinforced concrete.

The advantage of carbon fiber reinforcement over steel, polypropylene or glass fiber is in finishability, thermal resistance, weatherability, ability to mix high volume fractions and long-term chemical stability in alkaline and other chemically aggressive environments. Further, the use of carbon fiber is not associated with any potential health hazards as is the use of asbestos fibers. These benefits along with the reported improvements in the mechanical properties make carbon fiber reinforcement a propitious proposition.

Given the improvements of the mechanical properties of weak and brittle cement matrices by carbon fiber reinforcing and the physical properties of these composites, there are numerous possible uses. One of the major uses of these composites is in thin precast products like roofing sheets, panels, tiles, curtain walls, ferrocements, waveabsorbers, permanent forms, free-access floor panels, and I and L-shaped beams. The first large scale application of CRFC was in the form of panels with tile cladding in the Al Shaheed Monument in Iraq. CFRC curtain walls have been used in Japan for some time now.

In the cast in place applications, CFRC has potential for use in mortars for external walls especially for structures in seismic regions, for thin repairs, for small machinery foundations, etc. The good conductivity of these composites may be put to use in the secondary anode system in the cathodic protection of reinforced concrete bridge decks, in conductive floor panels systems and also in the concrete for lightning arresters.

Carbon fiber reinforced cement composite (CFRC) is lighter in weight and higher in tensile and flexural strengths than ordinary concrete. Therefore many researches are under way in Japan to find applications of CFRC as construction material. Among other applications, the possibility of using CFRC to make thin and light-weight curtain walls taking advantage of its higher flexural strength has been verified in experiments by many researchers.

A similar idea is also proposed for the thesis. A carbon fiber cellular mesh structure, fabricated for each floor slab, is attached to the fiber-reinforcement from the concrete to produce a donut-form cell. More details will be explained in later chapters.

fabrication

MOLDING :
Molding is the process of constructing a part within a mold. Typically, precut reinforcement is placed one layer at a time into the mold and saturated with resin. When the part has achieved the desired thickness and orientation, it is left to cure. When it is demolded, it will have the exact shape of the mold surface.

LAMINATING :
Laminating originally referred to applying a thin protective coating of resin and reinforcement over a surface such as wood. The term's use has broadened to include virtually any finished composite part, molded or otherwise. A current example would be: "The part tested was a 10-ply vacuum bagged laminate."

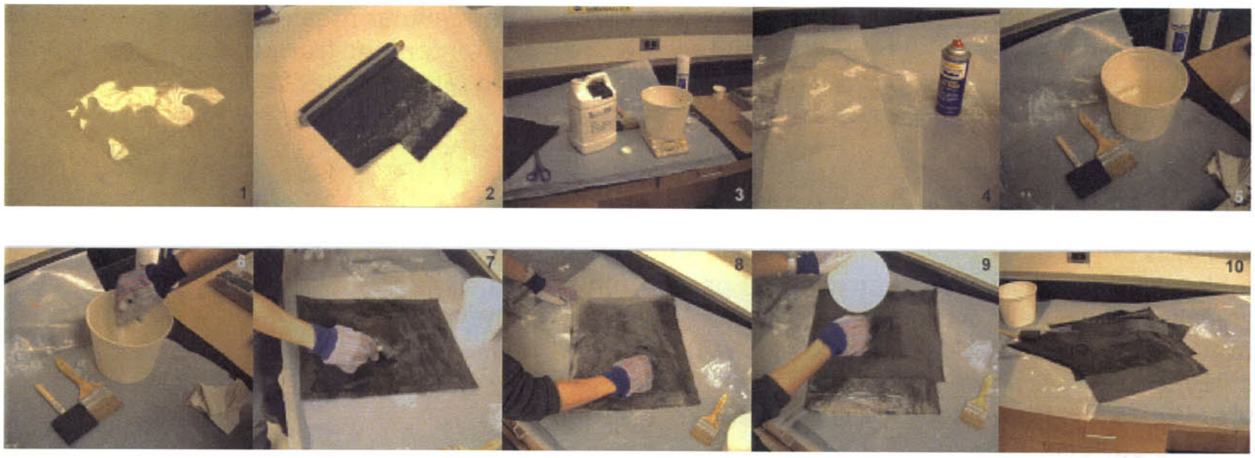
CASTING :
Casting refers to pouring a large mass of resin into a cavity. The cavity can be a mold when casting parts, or it can be the backside filler for a tool when making the mold itself. Specialized casting resins are necessary which generate less heat during their cure and thus create less distortion in the final part. Fibrous fillers can be added as needed to strengthen the casting.

SCULPTING :
Sculpting is usually accomplished by carving a shape out of polyurethane foam and then laminating the surface. This can be done to create a plug for the molding process, or to shape a finished part in the case of moldless construction.

[2.6] The NDE (Non-Destructive Evaluation) Lab is located on the basement level of Building 1.

In order to fully explore the properties of composites, I sought the help of Professor Shi-chang Wooh who teaches the High-Performance Composite Structures class in the Department of Civil and Environmental Engineering at MIT. Assisted by one of his Ph. D candidates Mark Orwat, I was able to produce one of my own carbon fiber panels in Prof. Wooh's NDE (Non-Destructive Evaluation) Lab.

The procedures are as follows:
1. prepare mold, spray with Teflon or similar release agents
2. cut carbon fiber fabric in the appropriate sizes
3. mix up epoxy resin with the appropriate combination ratios
4. apply mixed resin to the underside of the fabric with a brush
5. lay wet fabric on top of the mold and apply more resin to the top of the fabric
6. use a roller to eliminate air voids

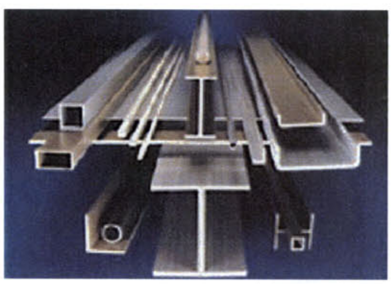


[2.7] Procedures of making a carbon fiber panel

7. apply another layer of fabric if necessary and repeat adding resin to the fabric
8. let the fabric cure for 3-4 days
9. apply addition paint or coating if necessary

In addition to this above method of molding and laminating, pultrusion of fiber is another way to produce composite products.

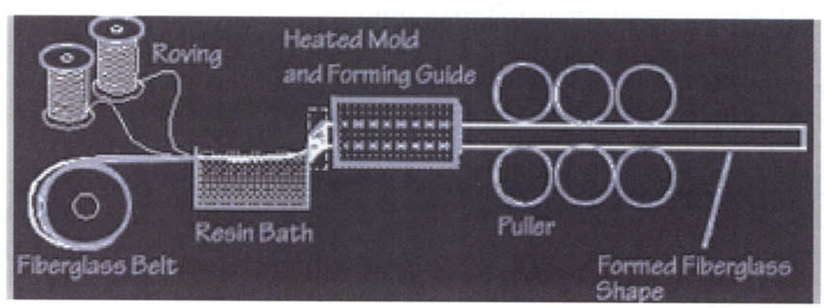
[2.8] pultruded samples



Pultrusion is a manufacturing process for producing continuous lengths of reinforced plastic structural shapes with constant cross-sections. Raw materials are a liquid resin mixture (containing resin, fillers and specialized additives) and flexible textile reinforcing fibers. The process involves pulling these raw materials (rather than pushing, as is the case in extrusion) through a heated steel forming die using a continuous pulling device. The reinforcement materials are in continuous forms such as rolls of fiberglass mat and doffs of fiberglass roving. As the reinforcements are saturated with the resin mixture ("wet-out") in the resin bath and pulled through the die, the gelation, or hardening, of the resin is initiated by the heat from the die and a rigid, cured profile is formed that corresponds to the shape of the die. A diagram of the process is illustrated below.

[2.9] the pultrusion process

(The energy used to produce a pultruded composite profile is 1/4 compared to steel and 1/6 compared to aluminium. The pultrusion process ensures stability of dimension, precisely placed fibres and a smooth, closed surface. Colouring is possible by means of pigments.)



[2.10] the pultrusion process diagram

applications

For more than twenty years, most of fiber production has been used in the aircraft and aerospace industries, where its relatively high cost can be justified by saving in weight. These industries are able to show that the fiber composite materials are cost-effective in selected areas, which accounts for the high level of interest being shown. However, nowadays, the material is become very common for other applications.

Aircraft/Aerospace:

Military, homebuilt, experimental, and commercial aircraft have used composite materials for years. The skeleton of the x-33 (shown on the left) is manufactured from extremely strong and durable graphite/epoxy composite material that is 50% lighter than other commonly used materials. Trusses between the propellant tanks tie the tanks together, while additional trusses between the liquid hydrogen tanks, the aerospike engines, and the liquid oxygen tank distribute the stresses among the different parts of the vehicle. The thermal protection system is suspended around this entire setup by a stand-off structure also constructed of composites.

[2.11] x-33 spacecraft

(The X-33 advanced technology demonstrator vehicle is a prototype reusable space plane.)

[2.12] Ducati Superbike 996

Art:

Stage sets, amusement parks, museums, and zoos find fiberglass easy to use and able to withstand outdoor environments when necessary.

[2.13] McLaren F-1 race car

Automotive:

Car and motorcycle racing have used composites extensively. Buses, trucks, and bicycles have found increasing use for composites. Race cars chassis have been made with composites for some time now. Even consumer car manufacturers such as Porsche and Mercedes are beginning to use composites for their interiors and chassis.

[2.14] Porsche 911 interior

Carbon fiber reinforcement has been used by Glass Fiber Engineering Ltd. in the construction of the Ford GT 40 body. The weight of the carbon fiber amounted to less than 1 lb, but the resultant gain in strength allowed a body to be made having a thinner section, giving a weight saving over 50 lb; moreover, the body was actually stronger than the original one and had greater freedom from vibration. The car finally won the race in Le Mans.

[2.15] Porsche 980

Industrial:

The unique corrosion resistance, strength-to-weight, electrical conductivity, and formability of composites lend themselves to an increasing variety of industrial applications.

Marine:

Boats, jet skis, paddles, canoes, kayaks, and buoys are a wide variety of examples where the ability to withstand prolonged exposure to water, salt, gasoline, chlorine, and ultraviolet light is critical.

Radio Control:

Radio controlled aircraft, boats, and cars use composites extensively to obtain the critical reduction of weight.

Sports Equipment:

Skis, snowboards, tennis rackets, surfboards, golf shafts... are mostly made of composites.

[2.16] Quicksilver racecraft

[2.17] Dragonfly snowboard by Burton

[2.20] golf club by Ben Hogan

[2.18] Vision SLR concept car by Mercedes-Benz

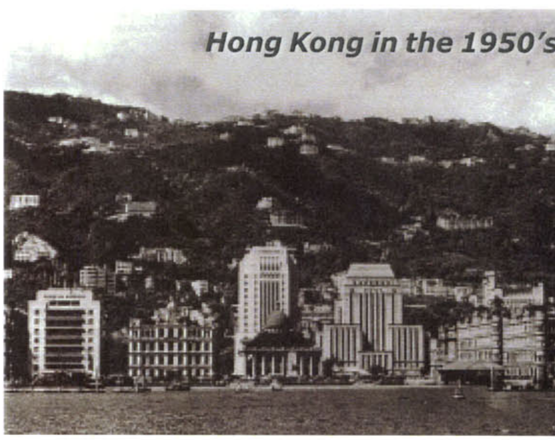
[2.19] composite plane by Boeing

[3.0]

[Central, Hong Kong]

[the "escalator"]

Hong Kong in the 1950's vs. 2001....



[3.1]

[3.2]

Central, Hong Kong

The thesis project will initially be realized on a site that is located in the heart of the Central district in Hong Kong Special Administrative Region, Peoples Republic of China.

Situated on southeast coast of China, Hong Kong has become one of the world's most densely populated cities. Also known as the capital of Hong Kong, the Central district of Hong Kong is the location for the central business district, high-end residential developments, major hotels, restaurants and shopping centers, as well as the busiest node of public transportation systems. Aside from being situated close to the seismic region, Hong Kong also has high windloads during the humid summer seasons due to frequent typoons.

[3.3] The typical fast-paced Hong Kong population goes to work in Central.

Important factors of the site on the project:

1. Location of nodal point in Central
2. Typhoons and seismic activities
3. High land value demands quick assembly of buildings
4. High density site constraints (crowded and less-than-ideal environment)

[3.4] skyline of Hong Kong

Simlilar to other metropolitan cities, construction speed is a factor of prime importance in the Hong Kong building process, even outweighting the factor of quality. 'Time is Money' is the slogan for the rich developers who are continuously protruding buildings to re-shape Hong Kong's skyline. The amazing speed of construction is as fast as 3 to 4 days per concreting cycle for a typical floor. For example, the Citibank Plaza under construction in 1991 in Central was going up at the 3 day-cycle.

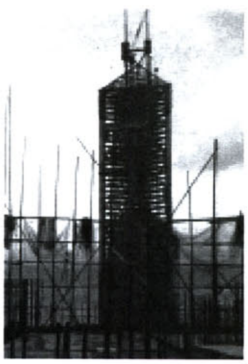
[3.5] Citibank Plaza during construction

Located right next to Pei's Bank of China, Citibank Plaza is built using the traditional method of bamboo scoffolding.

A review of the high land cost would explain the emphasis on time. For example, the particular site of around 670 square meters in Wanchai for the tallest office building was acquired at a government auction on 25th January 1989 at a price of HK$ 3,350,000,000.00 or HK$ 5,000,000.00 per square meter site area. (approximately US$ 60,000 per square feet) The interest alone on the land cost around HK$ 918,000.00 (or US$ 118,000) per day at the prime rate of 10%. This would give enough pressure to produce a fast-track building (at 4 day-cycle per floor).

Due to the high land cost, developers and architects have constantly worked their way through legal restrictions (basically the Building Ordinance) to fish for possible developable areas.

left: [3.7] The city is so dense that the width of a typical site in Central is only as long as the length of a minivan. *right:* [3.8] Looking down at the Victoria Harbor from the peak, one can then realize the abundance of high-rise buildings.



[3.8] Bank of China during construction

No matter how advanced technology may be or how intelligent buildings are designed to be, the average Hong Kong building (including Pei's Bank of China tower) still employs a lot of labor intensive trades. Bamboo scaffolding, plywood formwork, cutting of reinforcement bars, sawing of timber planks, spay painting, hanging up mosaic tiles, etc. - all the familiar scene in Hong Kong construction sites.

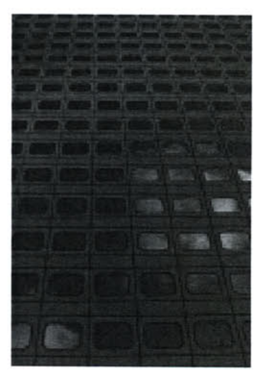
Traditional building materials in Hong Kong:

Residential and institutional: external wall tiles
high-end residential: granite and glass
Commercial: aluminum cladding, glass curtain wall system

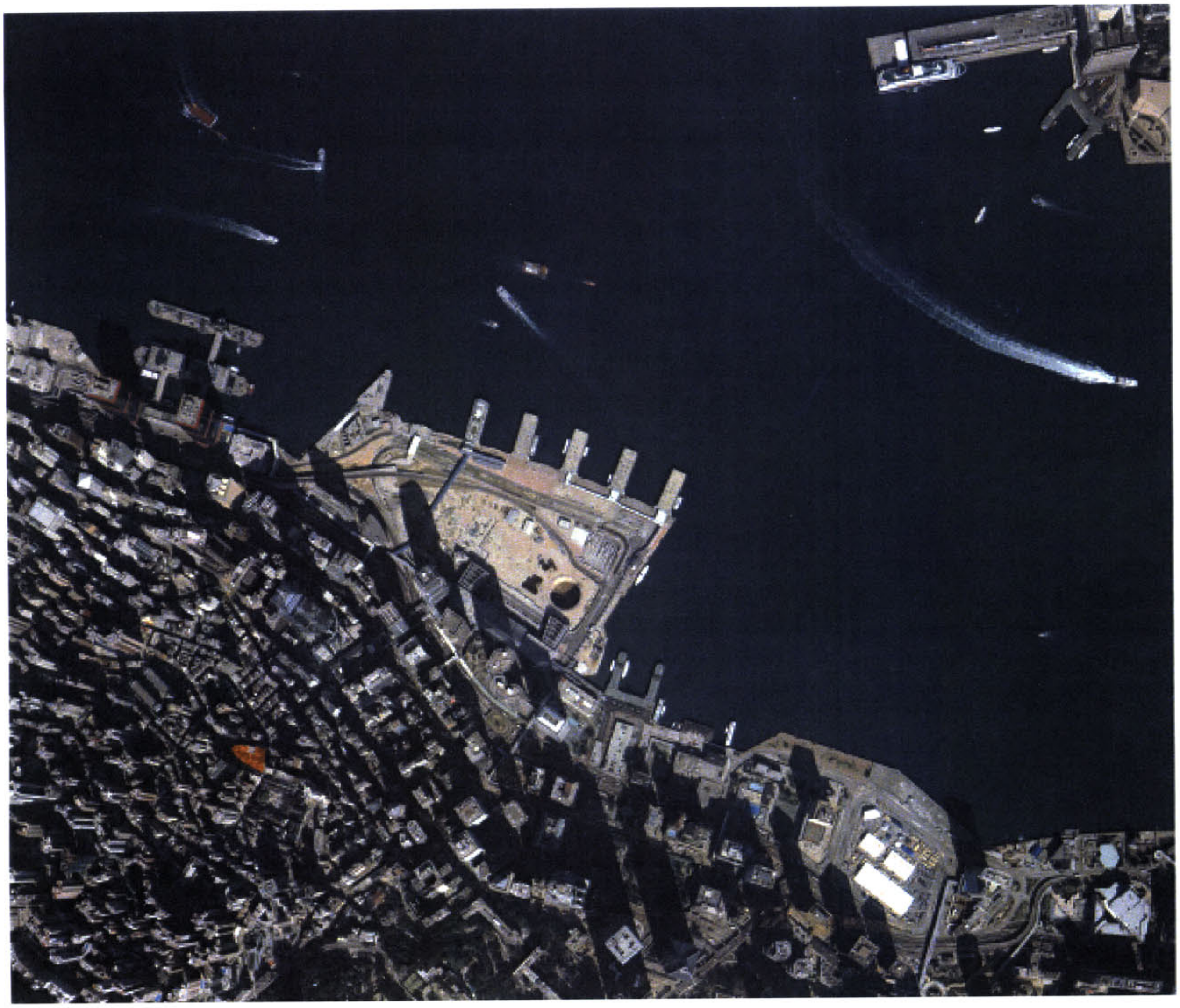
[3.9]Bamboo scaffolding

[3.10]Typical housing estate in Hong Kong

[3.11] Middle-class residences



[3.12] Commercial office tower facade



[3.13] aerial photograph of the site

Located on the northern part of Hong Kong island, the site of the project (colored in orange in above aerial photograph) is located at the corner of Hollywood Road and Lydhurst Street in Central.

PERCENTAGE SITE COVERAGES AND PLOT RATIOS

Height of building in metres	Domestic buildings						Non-domestic buildings					
	Percentage site coverage			Plot ratio			Percentage site coverage			Plot ratio		
	Class A site	Class B site	Class C site	Class A site	Class B site	Class C site	Class A site	Class B site	Class C site	Class A site	Class B site	Class C site
Not exceeding 15 m	66.6	75	80	3.3	3.75	4.0	100	100	100	5	5	5
Over 15 m but not exceeding 18 m	60	67	72	3.6	4.0	4.3	97.5	97.5	97.5	5.8	5.8	5.8
Over 18 m but not exceeding 21 m	56	62	67	3.9	4.3	4.7	95	95	95	6.7	6.7	6.7
Over 21 m but not exceeding 24 m	52	58	63	4.2	4.6	5.0	92	92	92	7.4	7.4	7.4
Over 24 m but not exceeding 27 m	49	55	59	4.4	4.9	5.3	89	90	90	8.0	8.1	8.1
Over 27 m but not exceeding 30 m	46	52	55	4.6	5.2	5.5	85	87	88	8.5	8.7	8.8
Over 30 m but not exceeding 36 m	42	47.5	50	5.0	5.7	6.0	80	82.5	85	9.5	9.9	10.2
Over 36 m but not exceeding 43 m	39	44	47	5.4	6.1	6.5	75	77.5	80	10.5	10.8	11.2
Over 43 m but not exceeding 49 m	37	41	44	5.9	6.5	7.0	69	72.5	75	11.0	11.6	12.0
Over 49 m but not exceeding 55 m	35	39	42	6.3	7.0	7.5	64	67.5	70	11.5	12.1	12.6
Over 55 m but not exceeding 61 m	34	38	41	6.8	7.6	8.0	60	62.5	65	12.2	12.5	13.0
Over 61 m	33.33	37.5	40	8.0	9.0	10.0	60	62.5	65	15	15	15

[3.14] Building Ordinance

According to the Building Ordinance, it is categorized as a class C site within zone 1; means a corner site that abuts on streets none of which is less than 4.5 m wide in the most developed area that has minimum parking requirement. Open area for a "Class C" site is required to be not less than 1/4 of roof-over area of building.

Besides being the financial and retail node of Hong Kong, the Central district also offers a lot of other unique characteristics not found in other Asian cities.

For example, discover a wealth of oriental art and crafts within the narrow network of alley south of the CBD. Areas dedicated to Asian antiquities, such as Hollywood Road, offer glimpses of bygone eras. Bargain for a Ming-dynasty vase or contemplate the classical beauty of traditional Chinese furniture. A collector's paradise, knick-knacks from days gone by are piled floor to ceiling in shops, tucked away from the casual observer.

[3.15] One of the Chinese furniture store located on Hollywood Road always attracts tourists from all around the world.

Hong Kong offers stunning artifacts and ornaments from China and Asia, and being at the centre of this rich cultural heritage, makes it an ideal location for household luxuries from. It is also a haven of affordable and competitively priced goods for making your house a home.

Furniture warehouses in other parts of the city such as Aberdeen and Ap Lei Chau stock everything you need from everyday items to extravagances. Having a one-of-a-kind set of dinner or teaware is possible at the porcelain factories. And you can select from solid or simple wood veneer pieces when ordering custom-made furniture.

[3.16] The Starck-designed restaurant *Felix* in Tsim Sha Tsui offers a celebrity-style dining experience.

Lan Kwai Fong

This city that lives to eat has an incredible variety of restaurants, east and west, from fast food stalls and intimate bistros to elegant dining rooms.

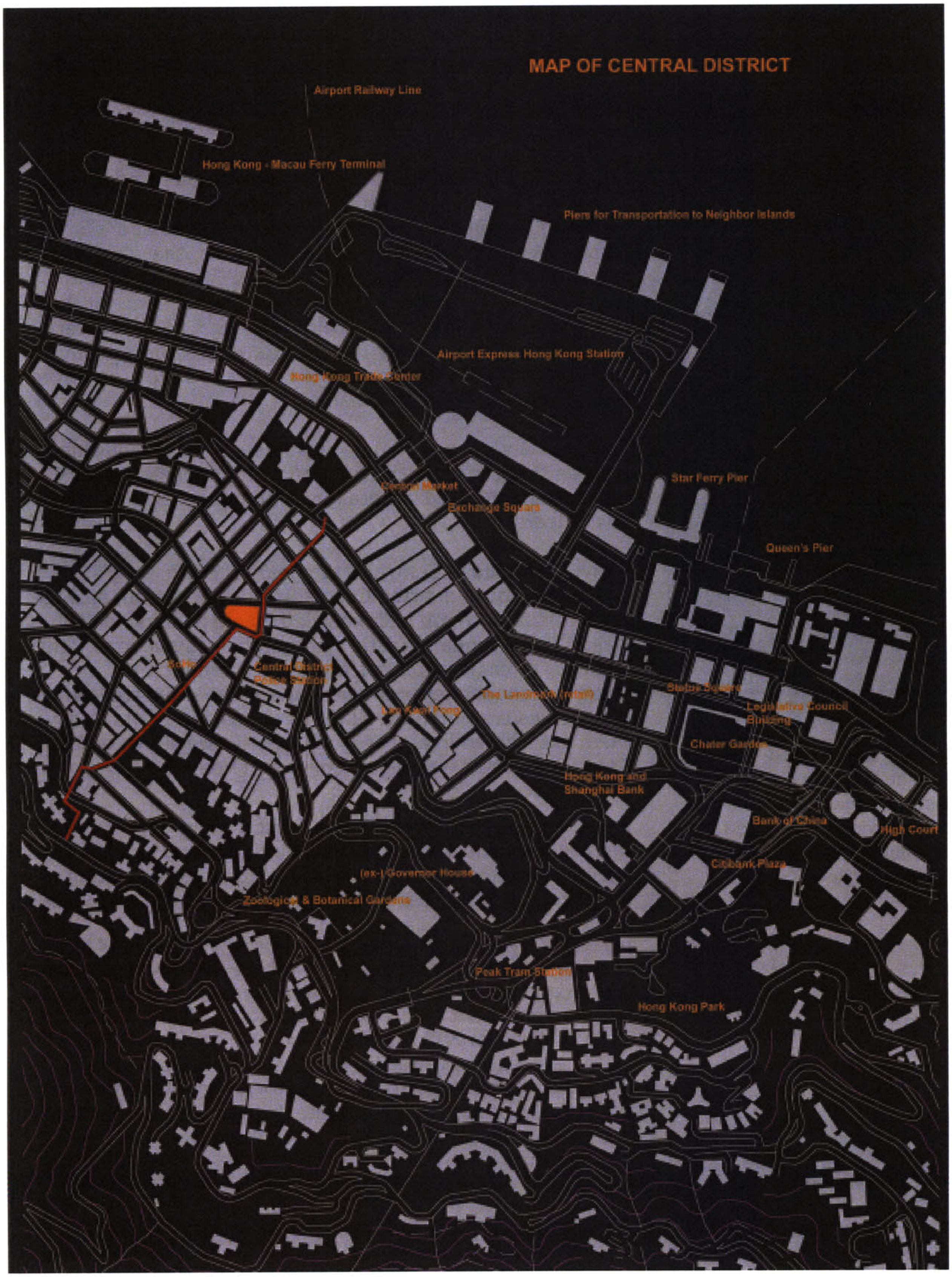
Welcome to the feast. The chic food quarter of Lan Kwai Fong in Central District is a gastronome's delight with stylish restaurants, theme bars and corner coffee shops.

Informal restaurants operate in Hong Kong's many food and nightlife areas, such as Kowloon City (especially for Asian food) and Tsim Sha Tsui in Kowloon and Wan Chai and Causeway Bay on Hong Kong Island. Some of the most fashionable restaurants, as well as clubs and bars, are found in Lan Kwai Fong, a thriving nightlife area near Central District where the action spills out into the cobblestone streets, and carries on until dawn. Hong Kong's newest

[3.17] The Lan Kwai Fong area has become the place to hang out for people of all ages.

[3.18]

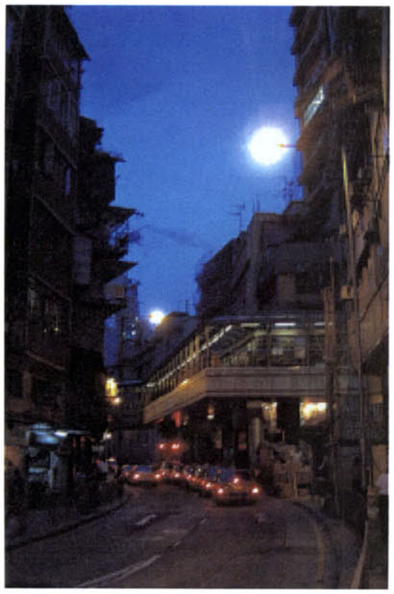
[3.19]



[3.20] site plan of the Central district dining area is SoHo (South of Hollywood Road), a rapidly growing center of Asian and Western restaurants just above Lan Kwai Fong.

Hollywood Road

Hong Kong's SoHo ("South of Hollywood Road" around Staunton and Elgin streets) joins other international capitals in offering a compact, fashionable area of bars and restaurants. Once a warren of shophouses, the streets around Hong Kong's Central-Mid-Levels Escalator (the world's longest outdoor escalator) now boast some of the city's best and most intimate dining spots. Cheerful exteriors open into small speciality restaurants where you can savour dishes from the Himalayas to the Louisiana bayou, and from Malaysia to the Mediterranean.



[3.21] The elevated walkway is stretched around the eastern boundary of the site, thus providing an opportunity for multiply entry/exit points at different levels.

Then make your way to Hollywood Road, the hub of Chinese antique shops in central Hong Kong, where dealers are willing to haggle and generally sell items for less than the auctioneers.

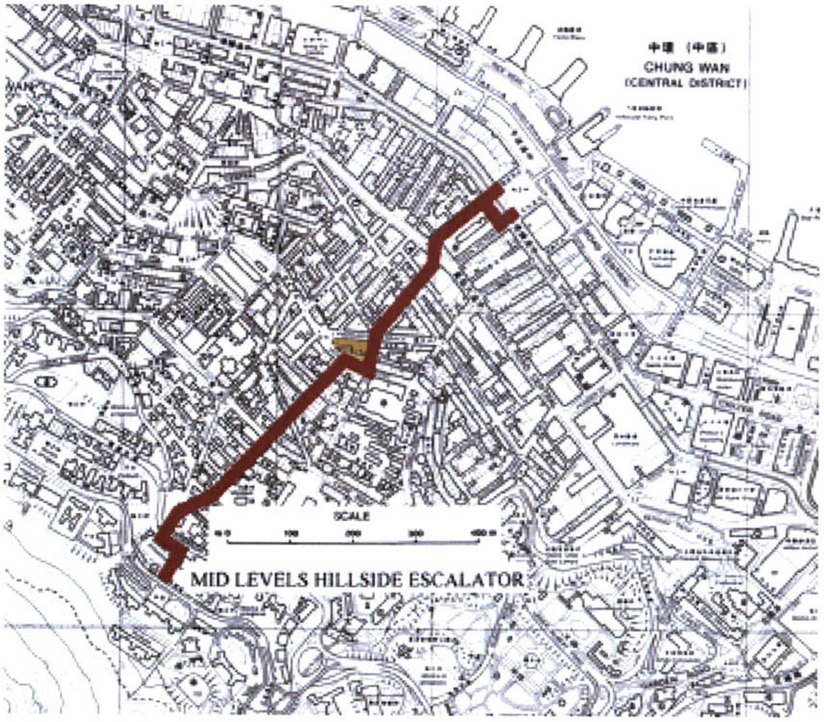
Hollywood Road in Central is the heart of Hong Kong's thriving antiques quarter. Collectors flock here from all over the world to hob-nob with knowledgeable dealers and to attend the biannual Christie's and Sotheby's auctions. There is plenty of choice, too, for those on a budget and energetic enough to rummage through the small stalls and dark stores crammed chock full of curios and crafts. Many of them are located in and around Upper Lascar Row, or Cat Street about half way along Hollywood Road.

From the rare items offered by Christie's and Sotheby's to the naive charm of Chinese folk painting, Hong Kong is an exciting place for all sorts of art. Befitting its reputation as a meeting point for East and West, the art-scene is dynamic and varied.

It is precisely this combination of mixed-use environments at this location that enables a communal gathering as well as a private apartment complexes to operate. While part of the podium levels provide spaces for retail, restaurants and public access, the tower on top houses more private activites. A sculptural form of the tower could then be desirable in order to demonstrate itself as a nodal point and allow for interactions that are appropriate for a high-density site like this.

[3.22] Alleys only for pedestrian access are very common in the Central District. This image illustrates the close proximity between the elevated walkway and a nearby office tower.

the "escalator"

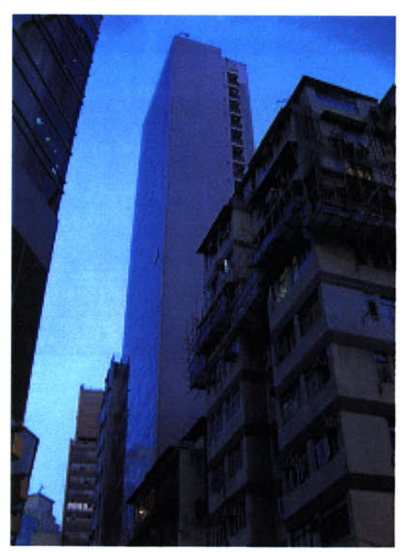


[3.23] map of the "escalator"

[3.24] The elevated walkway stretches into the CBD.

[3.25]

The escalator system provides a north-south pedestrian link between the Mid-levels and Central. It is 800m long and climbs to a height of 135m. The site of the project is located almost at the mid-point of the escalator, where the walkway formed a "notch" around the site. Most of the surrounding buildings are old mid-rise residential units, except for a newly constructed office tower. This office tower will be kept for the purpose of the project. The elevated walkway, extending over 1km into the pedestrian system has overpasses linking up a number of key commercial buildings within the Central Business District sitting on reclaimed land.



[3.26] The existing 25-story office building at the north of the site is to be kept to illustrate a less-than-ideal site condition common in high-density urban environments.

[3.27] Surrounding apartments and stores are within very close proximity to the elevated walkway.

[3.28]

[3.29]

The site of the project intersects at the mid point of the escalator (shown in red in the previous map). Existing apartments and stores are within very close proximity to the elevated structure and are visible to any passersby. Issues concerning the private and public domain are thus critical when one organizes various programmatic elements within the complex.

[4.0]

[concept]

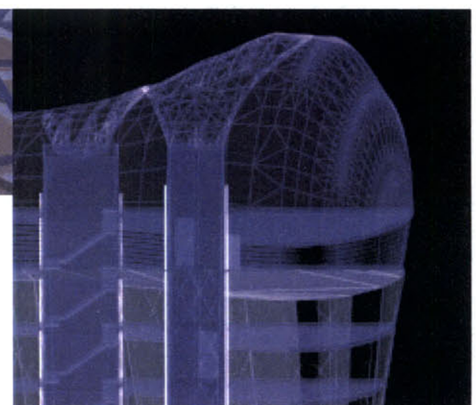
[program]

[diagram]

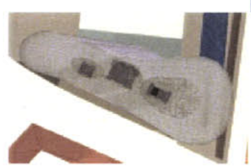
"A modern designer must be sensitive to attitudes to materials, resource use, ecology, usefulness, beauty, craft and technology, if he or she is to respond to the task with an intelligent solution."

- Ross Lovegrove

[4.1]



[4.2]



[4.3]

concept

The design of the building is generated through an integrated process of the following design directions:

1. the dynamism of the existing site:
the escalator, the existing office tower on the north, the sloping condition

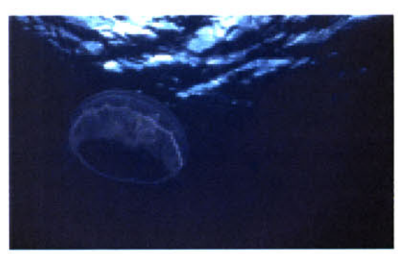
2. the programmatic organization:
public/private sectors for various activities that could be held within the complex

3. the properties and characteristics of the material:
design optimizes the structural and spatial flexibility

From the research of composites, it is understood that in order to utilize the material effectively, one should take full advantage of its tensile strength. However, one should also keep in mind that composites have very little or no compressive strength. A realistic way to approach the problem is to introduce a combination of tensile and compressive structural members to carry all the necessary loads. In this case, some kind of a concrete core structure is indispensable. The composite materials can then be used in the skin to carry any tensile loads.

The main challenge of the design is therefore to create a composite structural skin that carries the tensile loads of the building, and transfer the loads to a more convention concrete core system that carries the compressive loads. A similar idea of such a structure is evident in a jellyfish or a lantern, where a outer skin element transfers all the forces to the central core to maintain rigidity.

[4.4] Japanese lantern



[4.5] jellyfish

Option 1: Panel system

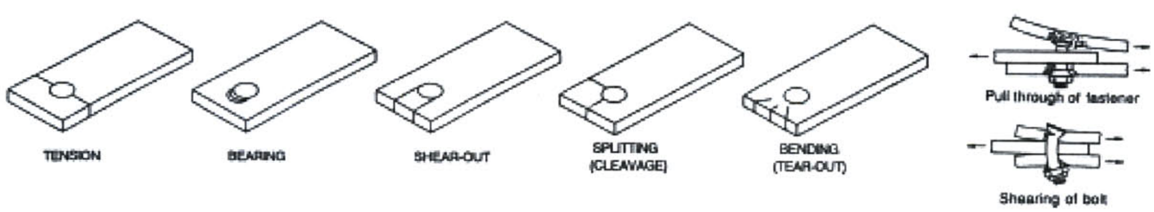
The first approach to the design of the structural skin is the panel system. As seen in most of Frank Gehry's buildings, curved curtain wall systems arranged in panels are commonly applied onto the building facades. The office tower for the Dutch insurance company, National Nederlanden in Prague, or commonly known as the "Fred and Ginger" building, uses curved glass panels on the facade to give the sculptural quality to the building.

[4.6] Frank O. Gehry's "Fred and Ginger" building

However, when one looks at most of these curtain wall sections, they all require another substructure to hold the wall up. In the "Fred and Ginger" building, the curved glass is not meant to be totally watertight, although it does act as a shield for controlling the environment within the interior watertight layer.

One hypothesis is that the skin could be prefabricated with Kevlar (for impact resistance) or carbon fiber and the fabric would be a custom-made three dimensional stitch so that the use of honeycomb substructure underneath can be eliminated. Individual pieces of the panel can be formed with molds with sizes up to 12 feet tall or more depending on the manufacturing facility. Polyurethane foam can be injected between the interior and exterior layers to provide necessary insulation. The ideal situation is that the whole skin of the tower can be fabricated as one whole piece, which is impossible to transport even if it can be fabricated. The formed panels will therefore have to be joined in some way. This is where the problems come in.

A composite panel gets its strength from the fiber reinforcement, such as carbon fiber or fiberglass. Any kind of mechanical joints require some kind of a hole that would introduce high stress concentrations around the drilled area. (Also see the *models - exploration models* section for clarification.) Another problem with the panel system is that when building a composite structural skin panel, one would be required to make openings for windows, which means cutting holes in the fiber reinforcement. This will significantly reduce the strength of the panel. Although one solution would be to add multiple layers of fabric around the holes or openings to create an amount of homogenous material to distribute the stress, the same cannot be applied when dealing with large openings such as windows. It is true that other methods of joining, such as adhesives and high-



[4.7] various modes of failure of bolted connections in polymer composites

strength tapes, can be possible alternatives. However, when considering the loads of a 20+ story high-rise building, one would require more testing to ensure stability.

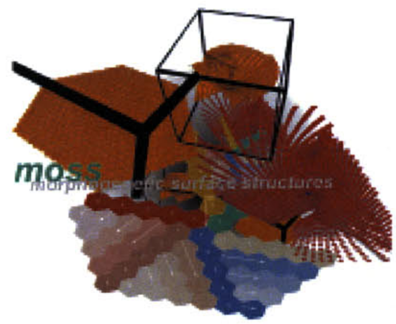
(* It is still possible to introduce a composite curtain wall skin system that is supported by another substructure. The composite panels would be much lighter than glass panels, but it would defeat the purpose for using such a material.)

Option 2: Mesh System

After much struggle, we came up with another idea that seems to be more feasible. The mesh system idea originates from my thesis supervisor Prof. Peter Testa, who conducted a studio involving surface structures.

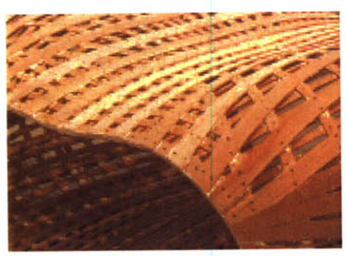
MoSS (Morphogenetic Surface Structures) is a research program to generatively model surfaces that actualize Lindenmeyer systems in an interactive environment. This environment adds controlled flexibility to the system which can emulate real world constraints. MoSS allows the designer to set a base grammar and guide growth through the application of boundary and field conditions. The modeling of multiple surfaces with variable grammars is implemented.MoSS outputs files to CAD/CAM applications allowing for three-dimensional testing in physical models. The investigative software is integrated with Alias|Wavefront Studio via the Applications Programming Interface of Studio which supports development in C++.

- Emergent Design Group (http://web.mit.edu/arch/eds/)



[4.8] MoSS from Emergent Design Group

The idea begins with looking at a mesh surface structure that is woven together like a piece of fabric. Strips of pultruded composites with constant sections will be used to form the structural mesh. A similar idea is used by artist Richard Deacon in his wooden chair below.

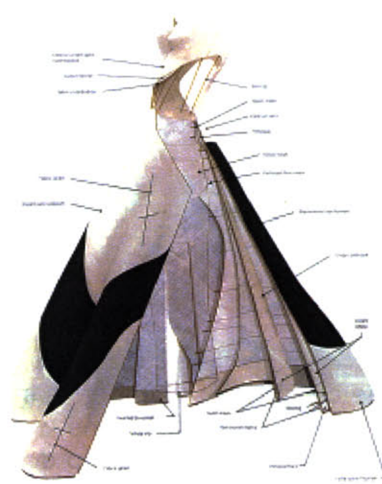


[4.10]

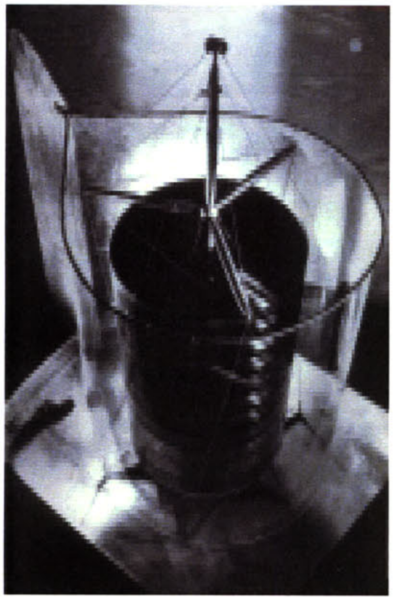
[4.11]

[4.9] Richard Deacon's wooden chair

This idea of structural mesh is not at all new. Woven baskets were invented years ago. The clothing industry has also been using a similar method to fabricate dresses. Designer Charles James uses whalebones as supports for his creations.



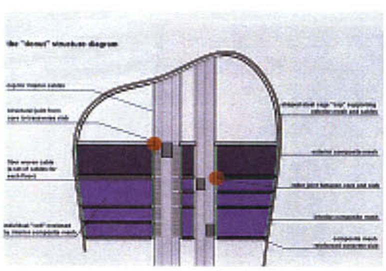
left: [4.12] Designer Charles James uses whalebones to support his dresses.
right: [4.13] Charles James' dress diagram



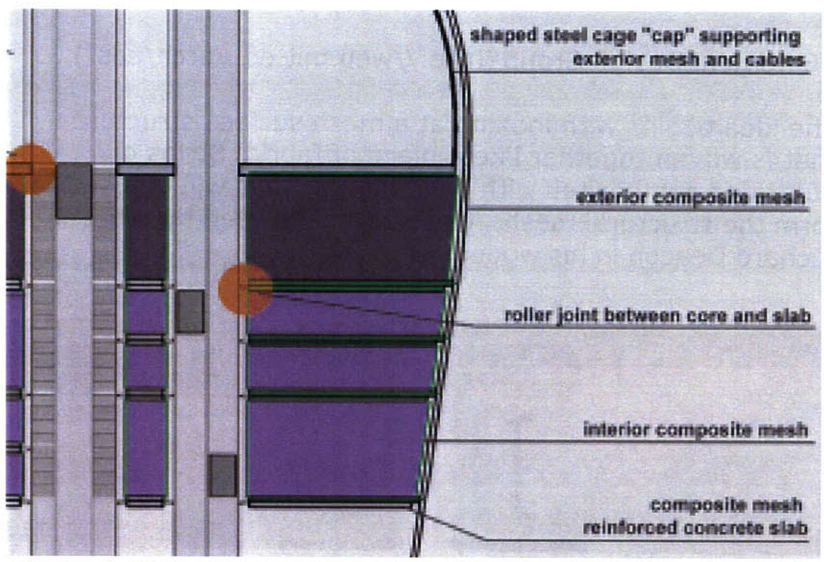
[4.14] R. Buckminster Fuller's suspension tower idea illustrates a symmetrical form that optimizes structure efficiency.

A few of the problems that are encountered with the panel system are solved with the mesh idea. First of all, openings in the skin becomes natural. Depending on the density of the structural mesh, the voids of the mesh can be simple be interpreted as openings. Nothing needs to be drilled or cut. Depending on the strength of the pultruded sections, and the distribution of loads acting on the tower, strips can be layered and the density of the mesh can vary accordingly.

In order for the composite mesh skin to perform structurally, it would need to be acting in tension. The idea is that all the dead loads of the building, i.e. the floor slabs, will be hung from the mesh and carbon fiber woven cables. The loads will then be transferred from the mesh and cables. Each floor slab has its own set of supporting cables connected to the cores as to prevent failure of the whole structure. The concrete cores will then take over the loads. Cellular mesh structure for each floor slab helps to retain rigidity of each floor cell.



[4.15]



[4.16] structural diagram

The components of the structural system includes (see *models - presentation renderings* section for more details):

1. Concrete core with composite reinforcements
2. Mushroom columns
3. Steel cage "cap"
4. Transverse slab
5. Interior cables
6. Exterior cables
7. Interior cellular mesh
8. Exterior cellular mesh

The construction sequence involved in this mesh system is also very different from convention constructions. Since all the floors are hung from the cores, the building is constructed from the top down.

It would be ideal if the whole length of each pultruded strip be fabricated as one continuous piece. However, that would be impossible for a 300 feet tall building (i.e. 600 feet long strip). At some point, a strip will need to be joined to another strip. The connection between strips of pultruded composites can be laminated or tied, similar to the idea of bamboo scaffolding using in traditional Hong Kong construction.


[4.17] tie connection for traditional bamboo scaffolding

A series of preliminary calculations is then performed to allow a better understanding of the magitude of the loads that are involved. The major loading of the tower is the dead load of all the floor slabs. Total volume of the slabs is calculated to estimate the total dead load of the building.

(*assuming the thickness of the slabs is 1 foot)

floor #	surface area (sq.ft.)	thickness of slab (ft)	volume (cu.ft)
1	8731.9	1	4366.0
2	8246.1	1	4123.1
3	7786.3	1	3893.2
4	7367.4	1	3683.7
5	6970.5	1	3485.3
6	6613.0	1	3306.5
7	6283.3	1	3141.7
8	5984.8	1	2992.4
9	5717.3	1	2858.7
10	5483.6	1	2741.8
11	5239.0	1	2619.5
12	5109.3	1	2554.7
13	4973.3	1	2486.7
14	4866.7	1	2433.4
15	4797.0	1	2398.5
16	4750.4	1	2375.2
17	4746.3	1	2373.2
18	4729.7	1	2364.9
19	4865.6	1	2432.8
20	4982.1	1	2491.1
21	5109.1	1	2554.6
22	5042.6	1	2521.3
23	5840.0	1	2920.0
	Total volume of slabs		**67117.7**

Using the above calculations of the total volume of the floor slabs, the density of the tensile composite members can then be estimated.

Density of lightweight concrete:
= 1750 kg/cu. m
= 1750 *(2.2/39.373)
= 0.06310 lb/cu. in.
= 109.0 lb/cu. ft.

Total volume of slabs = 68120 cu. ft.
Total surface area of tower = 80210 sq. ft.

(* assuming only 20% of the total surface area is to be covered with the structural mesh)

Total area of mesh surface = 80210 * (0.20)
= 16040 sq. ft.
= 27720000 sq. in.

Density of carbon fiber = 1.8 g/cu. cm.
= 1.8 / (2.543)
= 0.1098 g/cu. in.

Total weight of the exterior structural mesh
= 27720000 * 0.1098
= 3045000 g
= 6699 lb
= 3.35 tons (negligible)

Total weight of all floor slabs
= 67120 * 109.0
= 7320000 lb
= 3660 tons

With a safety factor of 2.0, the total dead load
= 3660 tons * 2.0
= 7316 tons
= 14600000 lbs

Tensile strength of carbon fiber composite
= 330 ksi

Load required = Strength * Area

Area = 14600000 / 330000
= 44.3 sq. in.

Assuming the number of vertical tensile members to be 24 per floor, each member will have a minimum cross-sectional area of **1.85** sq. in. (which is not much at all!)

scenarios

"Shopping will never die because it is a social thing."
- Rem Koolhaas. Wallpaper, July 2000

Best known for its tax-free shopping environment, Hong Kong is crowded with all kinds of retailing business. With the emergence of e-commerce, however, the shopping experience will definitely be going through some changes. One major setback of the e-retailing business is the delivery of goods. The good thing about shopping on the web is that one can browse, shop place orders and pay online twenty-four hours a day - quick and convenient. One will not need to wait in line, wait for the salesperson or wait for the store to open. However, after placing an order, one will then have to wait a few days for the product to be delivered.

The project therefore proposes a new type of shopping experience that happens within the complex. Located right at the nodal in the Central district of Hong Kong, the public podium levels not only provide the usual stores, but also a twenty-four hours "delivery center" which stores the things that one buys from the stores or the Internet. The customers have the options to have the goods delivered to their homes, or to be picked up by themselves - on their way to work or homes - any time of the day. The follow scenarios illustrate a few examples of how it works.

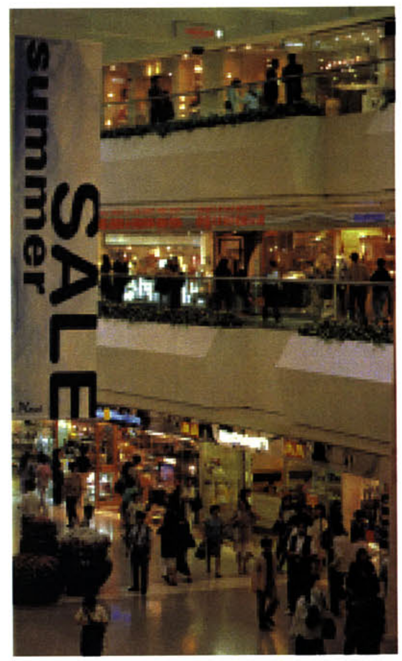
Scenario 01: Shopping still
Banks, travel agencies and estate agents will probably disappear. Instead, there will be an emergence of a mix of shops ranging from mega-store extravaganzas to local corner stores where you will have a personal account.

Scenario 02: Entertainment
You will go to your local electronic store, not to buy hardware, but to listen to CDs', watch DVDs' in the theater room and enjoy the surround-sound system.

Scenario 03: Retaining privacy
Your delivery center will hold a personal refrigerated locker, accessed by code. You will be able to order any goods and pick them up any time you like.

Scenario 04: Trying it on
Try on the clothes, light the candles and lounge on the pillows, then place your order and leave free of awkward paper bags.

Scenario 05: Picking up deliveries
Your grocery store will be your personal assistant, picking up your dry-cleaning and returning it with your food delivery.



[4.18] Pacific Place - a shopping arcade near Central

[4.19] Temporary stores on the cobblestone street in Central

Scenario 06: Chilling out

Hanging out in the coffee lounge will become a vital part of our day. We will be people-watching and gossiping. The high street will be a traffic-free zone, with bars and sandwich shops that never close.

program

Because of the location of the site and existing programmatic nature of the neighborhood, a mixed-use, adaptive program will be adopted. The bottom four podium levels will serve as a public space that could be utilized throughout the day. The first two stories consist of a combination of furniture galleries and boutiques and a tea lounge. The top two stories consist of a bar/restaurant and a "delivery center" which serves as a nodal community area. There are also sufficient open spaces which serves as a gathering, communal and recreational area. The idea is to create a series of spaces that can be flexible for efficient use at various times of the day. Located above the public domain will be a tower structure housing hotel suites/service apartments, work spaces, a private health club and a private function room that can be converted into a library/ wine bar. These service apartments aim at young professionals who enjoy the freedom of living alone in an area of nightlife and activities while at the same time staying close to work by any means of public transportation.

[4.20]

[4.21]

[4.22]

Boston's 61-room 15 Beacon hotel, for example, provides more of an unique experience than the usual Hyatt or the Four Seasons.

The recreational:

Stores will no longer keep their products on the premises to any significant degree. Instead, they become places of entertainment, decorated more like fun palaces than old emporia - places where you go to be coddled and cosied, to try on clothes and play around with gadgets and tuck into free sushi or a couple of cups of java while you figure out what you really think looks fabulous. Stores like Sony in New York and the Niketown in Chicago already have more tourists than they have shoppers. These tourists come to gawk and play and try out visions of fashion, sport or, in Sony's hermetically sealed bedroom of fun, gadgetry. At stores like this in the New High Street, after you've selected your purchases, you simply leave. It is up to the shop to get them to you.

Service apartments:

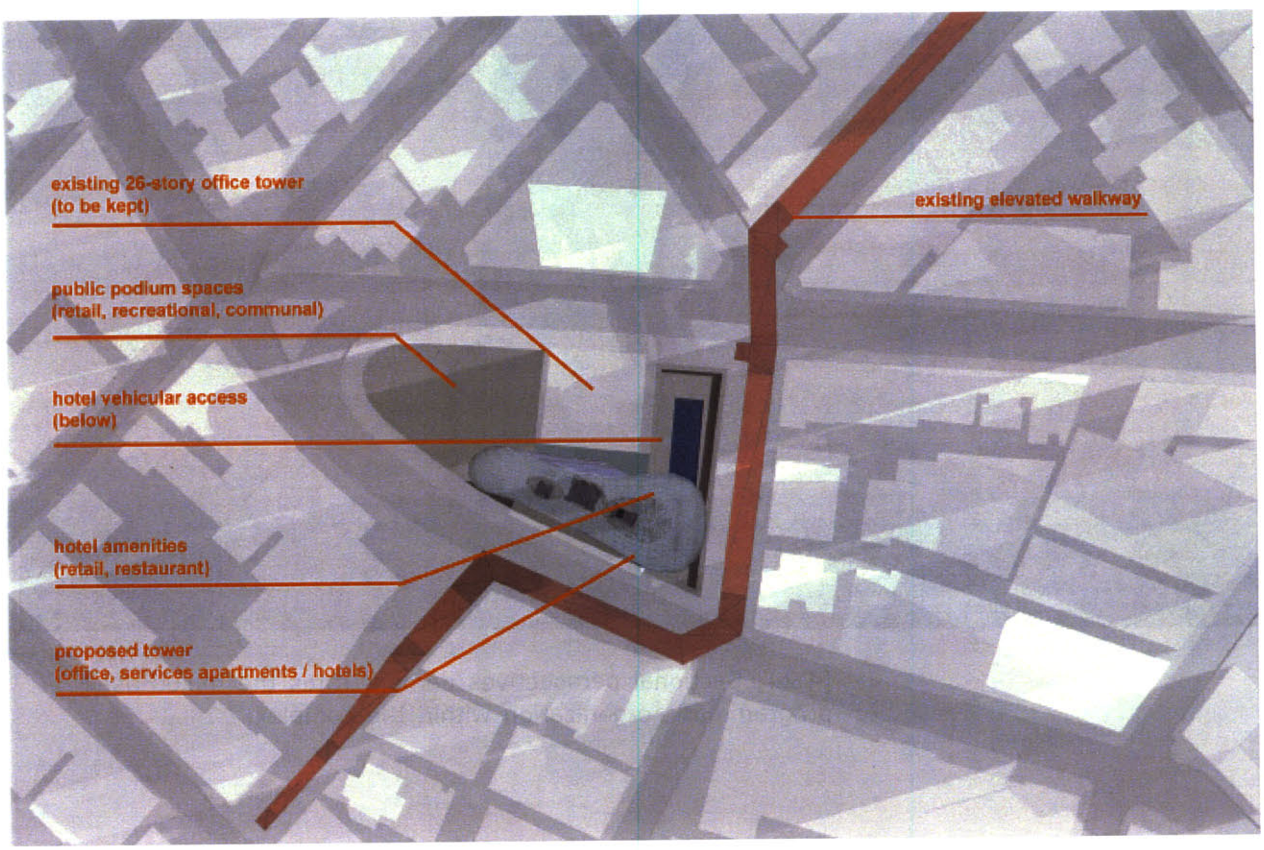
The emergence of boutique hotels as opposed to large-scale hotels has recently introduced a new way of temporary living when staying abroad. While these hotels offer more of unique accommodations within their individually-styled rooms, the scale of these hotels also facilitate better management and thus provides visitors with more personal services. For example, the Mercer Hotel in downtown New York and the 15 Beacon Hotel in Boston offer very different experiences than the Hyatt or the Four Seasons. On the other hand, the required site for one of these small-scale boutique hotels is more accommodating than a large-scale hotel when situated in an ultra-urban environment. With a smaller site, the location can thus be more ideal for these hotels. Targeting young entrepreneurs and professionals, these rooms can also provide an ideal, long-term living environment. While parking is not a requirement, the location and the services provided at these apartments offer both convenience and high quality of living.

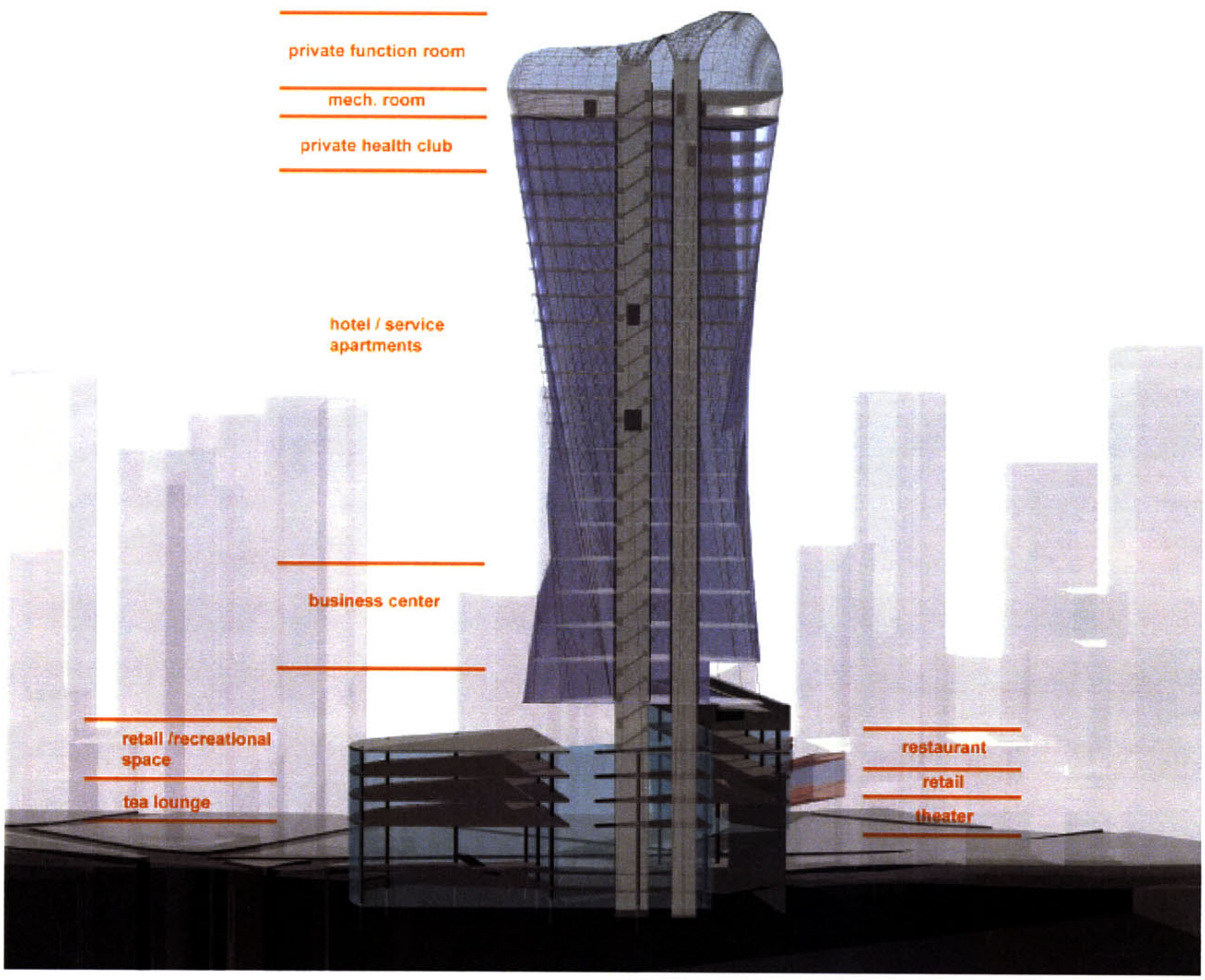
Workspaces:

With the booming of the information-technology and computing industries, smaller, rented, short-term cubicles as well as larger meeting spaces provided with high-end computer hardware, network and Internet connections are constantly in demand. The workspaces in the complex will provide small-scale businesses or individuals with the convenience and flexibility to work efficiently.

diagrams

[4.23] The site plan illustrates the massing components and accessibility within the site.





[4.24] Sectional perspectives demonstrates the mixed-use programmatic organization within the complex.

[5.0]

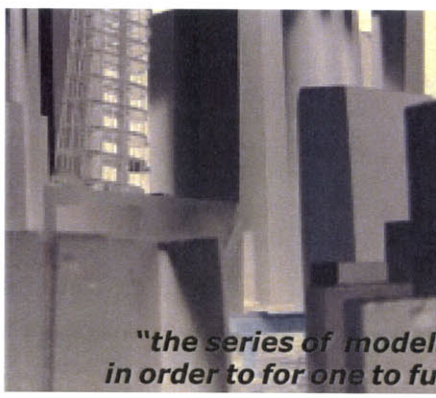
[exploratory models]

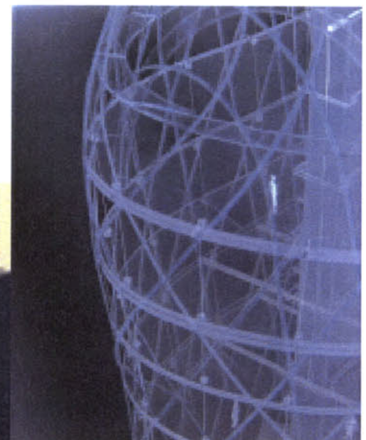
[presentation models]

[digital visualizations]

[presentation renderings]

[5.1]





[5.2]

"the series of models will have to operate in a variety of scales in order to for one to fully understand and explore the problem..."

[5.3]

Since there has never ever been a building constructed using fiber-reinforced plastics as structural elements, the exploration of the thesis project relies much on the construction of exploratory models and digital visualizations.

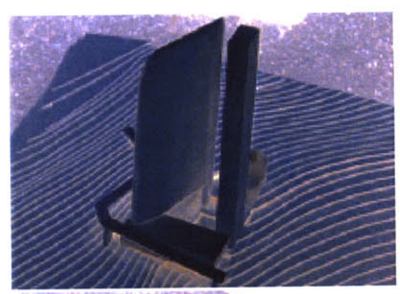
The physical models shown in this section are organized in chronological order. Various materials, such as chipboard, plexiglass, acrylic blocks, wood, canvas, brass tubes and stainless steel wires, etc. are explored in order to achieve the goals of each investigation. The techniques involved are also very diverse. The heatgun is used with plexiglass to create compound-curved surfaces, while the *Stratasys* 3D printer *FDM 2000* is used to produce complex solid phyiscal models which would be very difficult to produce using other methods or materials. At the same time, iterations of surface structures are generated quickly and evaluated in digital form. Moreover, since each floor plate of the tower varies in elevation, each had to be cut by the lasercutter to ensure accuracy. This is precisely why digital models and physical models are developed simultaneously. One can't live without the other.

The section is divided into four categories. Each shows the various stages of design developments in both physical and digital models.

exploratory models

Date: Sept. 20, 2000
massing model: chip board and wood
scale: 1/32" = 1'

[5.4]

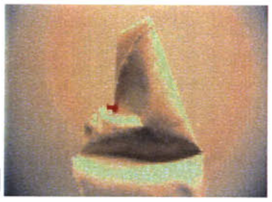


This is a simple massing model illustrating the basic programmatic organizations. Contours of the site is cut using the laser-cutter, and the massing of the buildings and the exisiting elevated escalator are both made in wood.

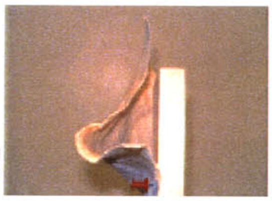
[5.5]

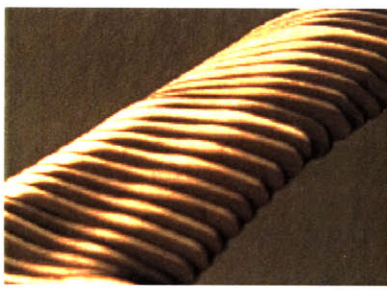
Date: September 24, 2000

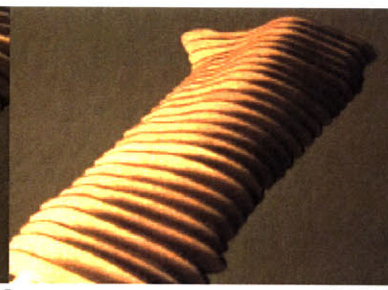
fabric model: canvas, liquitex, wood
scale: not to scale


[5.6]

This is a simple study model investigating the properties of a canvas fabric. The idea is to use the fabric as a skin that is supported by a wooden "core" and then the canvas is hardened with liquitex. This procedure of fabricating the "skin" is similar to the actual process of applying resin to composite fabrics.


[5.7]


[5.8]


[5.9]


[5.10]

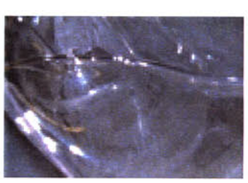
Date: Oct. 7, 2000

floor plate model: chipboard, wood
scale: 1/32" = 1'

This chipboard model investigates the shape of floor plates on different elevations of the tower. A 3D digital surface model is created first by lofting between the desired floor plates on two different levels. A planar surface is then used to section the surface every 10 feet, creating the profiles for all the floors of the tower for the lasercutting.


[5.11]


[5.12]


[5.13]

Date: Oct. 8, 2000

surface model 01: plexiglass
scale: no scale

This series of models introduces the use of plexiglass glass and heatgun to make compounded curves. The idea is that the monocoque structure of the plexiglass models represent a simliar skin/structure system of the tower. This technique of making compound-curved objects are later used for molds for creating fiberglass and carbon fiber models.

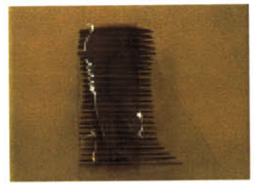
Date: Oct. 10, 2000

surface model 02: plexiglass
scale: 1/32" = 1'

This model illustrates the different possiblilities for surface structures. A piece of plexiglass is cut and placed on the chipboard model and is then heated with a heatgun. After heating for several minutes, the plex- begins to soften and take the form of the chipboard mold.

[5.14]

[5.15]



[5.16]

[5.17]

[5.18]

Date: Oct. 12, 2000

joint model: metal screws, plexiglass
scale: not to scale

These simple joint models illustrate the problem of connections with composite structural panels. Any holes that are created from a mechanical joint introduce huge stress concentrations around the area where an absence of reinforcing materialshighly reduces the strength of the panel. Moreover, in order to allow for flexibility between the panels, the connection mechanism will need to incorporate some kind of a damping device, or else any movement of the panels will introduce failure.

[5.19]

[5.20]

Date: Oct. 14, 2000

surface model 03: plastic
scale: 1/32" = 1'

Produced by the *StrataSys FDM 2000* 3D printer, this model shows the "shell" of the skin as a monocoque piece. One can then begin to experience the undulating surface when seen through the hollow object.

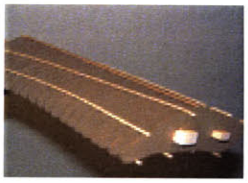
[5.21]

[5.22]

[5.23]

[5.24]

[5.25]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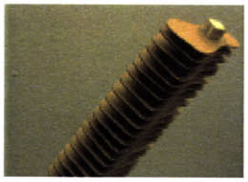
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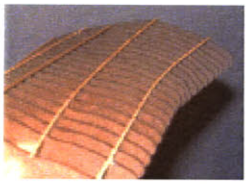
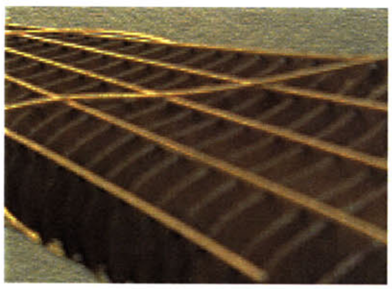
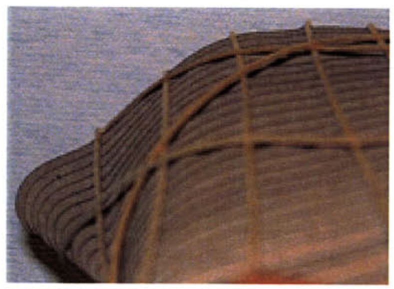

[5.28]

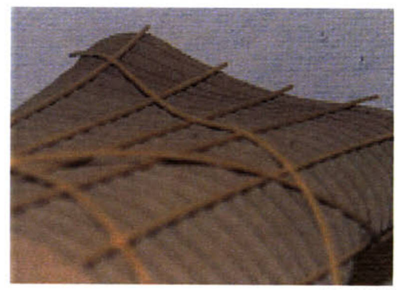
Date: Oct. 27, 2000

tower models: chipboard, wood
scale: 1/32" = 1'

These models illustrates the different ideas about the form-making process of the tower. Different configuration of the core as well as compound curved surfaces are explored. A slimmer form of the tower seems to give a better visual idea of the undulating surface.


[5.29]


[5.30]


[5.31]

Date: Oct. 28, 2000

tower structure model: chipboard, wood
scale: 1/32" = 1'

This model is built upon the tower form studies and structural strips are added to bring out the compound-curved skin surface. The floor slabs could be seen as ribs supported by the core and the vertical and diagonal strips are the substructure for the skin to rest on. The combination of the wooden strips and the horizontal plane also suggest a grid system of how the skin panels are shaped.


[5.32]


[5.33]


[5.34]

Date: Nov. 8, 2000

composite model 01: fiberglass, epoxy, plexiglass mold
scale: no scale

Created in the NDE (Non-Destructive Evaluation) Lab, the first of the composite models illustrates the molding possibility for the panel skin surface. The model has only one layer of fiberglass. The hole shows the location of the absence of the fiberglass fabric (only the epoxy resin).

[5.35]

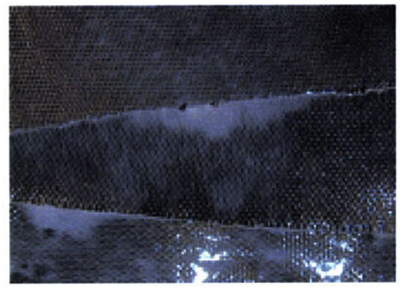
Date: Nov. 18, 2000

composite model 02: carbon fiber, epoxy, plexiglass mold
scale: no scale

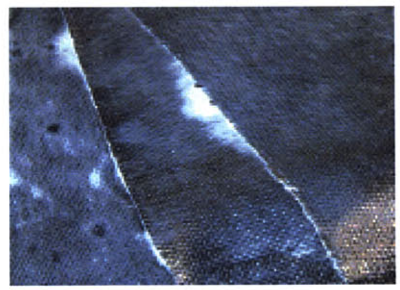
This carbon fiber panel model is an attempt to overlay several layers of uni-directional fabric in different directions to create a more homogenous material that has tensile strength in multiple directions.

* An obvious problem with structural composite panels is that any mechanical joint introduces stress concentrations around the hole. Although one solution is to add multiple layer of various directions to provide more homogenous materials to distribute the stress, the same could not be applied to large opening such as windows. One could still use the material for a curtain wall construction supported by another substructure, but that would defeat the purpose for using the material.

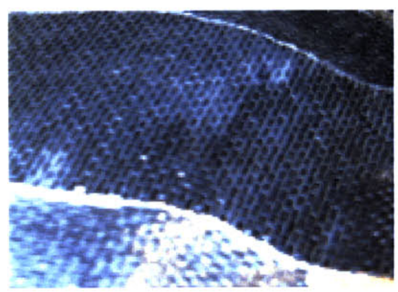
(see the *research* section for more details)



[5.36]



[5.37]



[5.38]

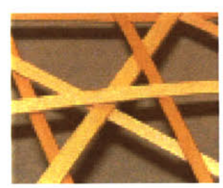
[5.39] carbon fiber weaving patterns

Date: Nov. 3, 2000

structural mesh model 01: wooden strips
scale: no scale

This model represents the structural skin mesh made with pultruded composite strips. Bass wood strips are woven to form a mesh that is structurally self-supporting. No adhesive is needed except at where two layers of strips (representing the primary vertical elements) are glued together. The pattern of the mesh comes from that of the carbon fiber fabric. Vertical strips are needed for the gravity loads, and the diagonal strip are needed for lateral reinforcements.

[5.40]



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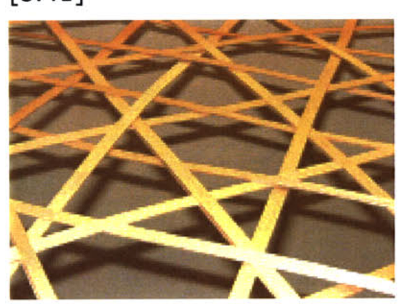
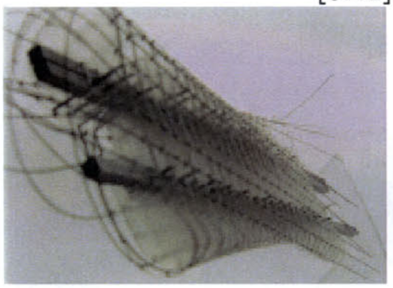
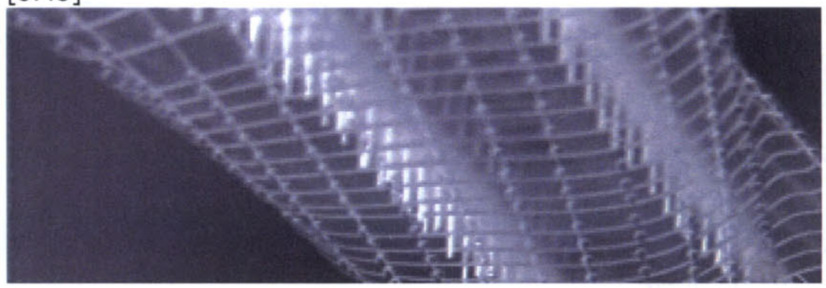


presentation models

[5.42]



[5.43]



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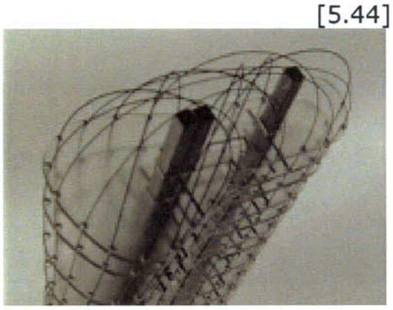
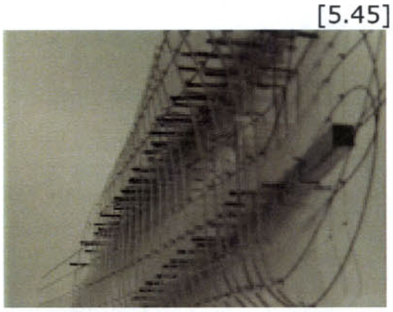


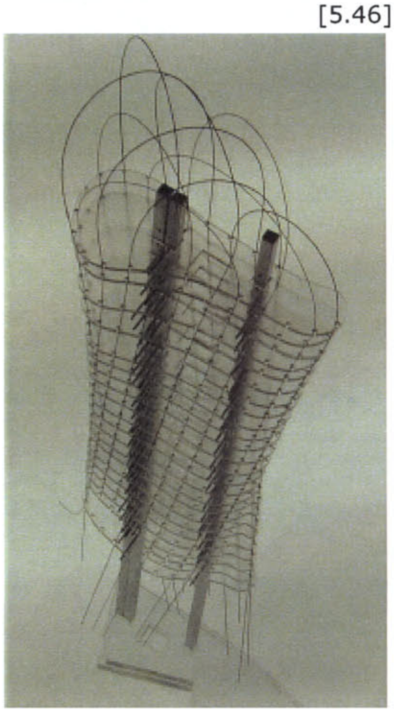
tower structure model: plexiglas, brass tubes, stainless steel wires
scale: 1" = 32'

[5.45]

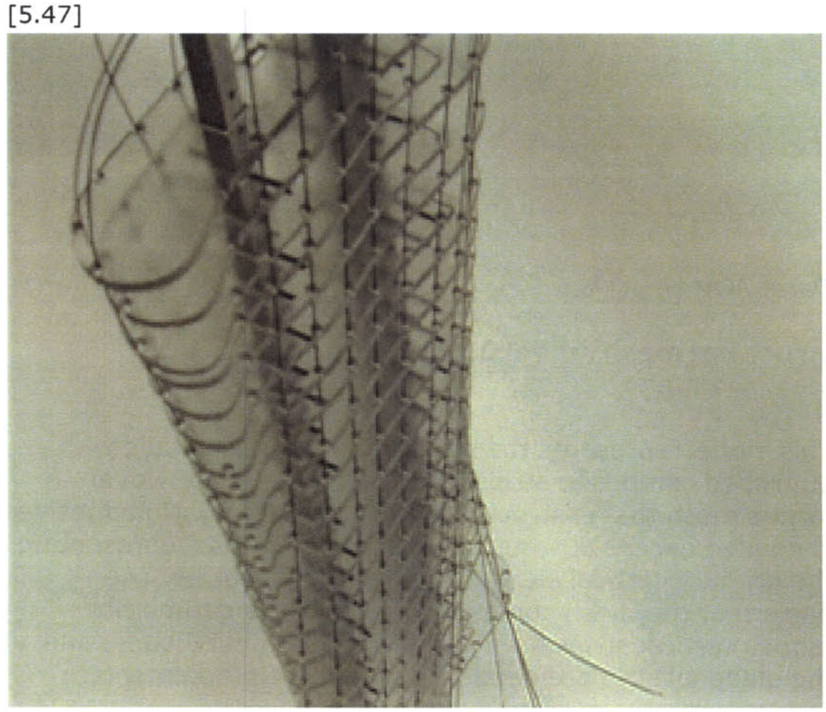


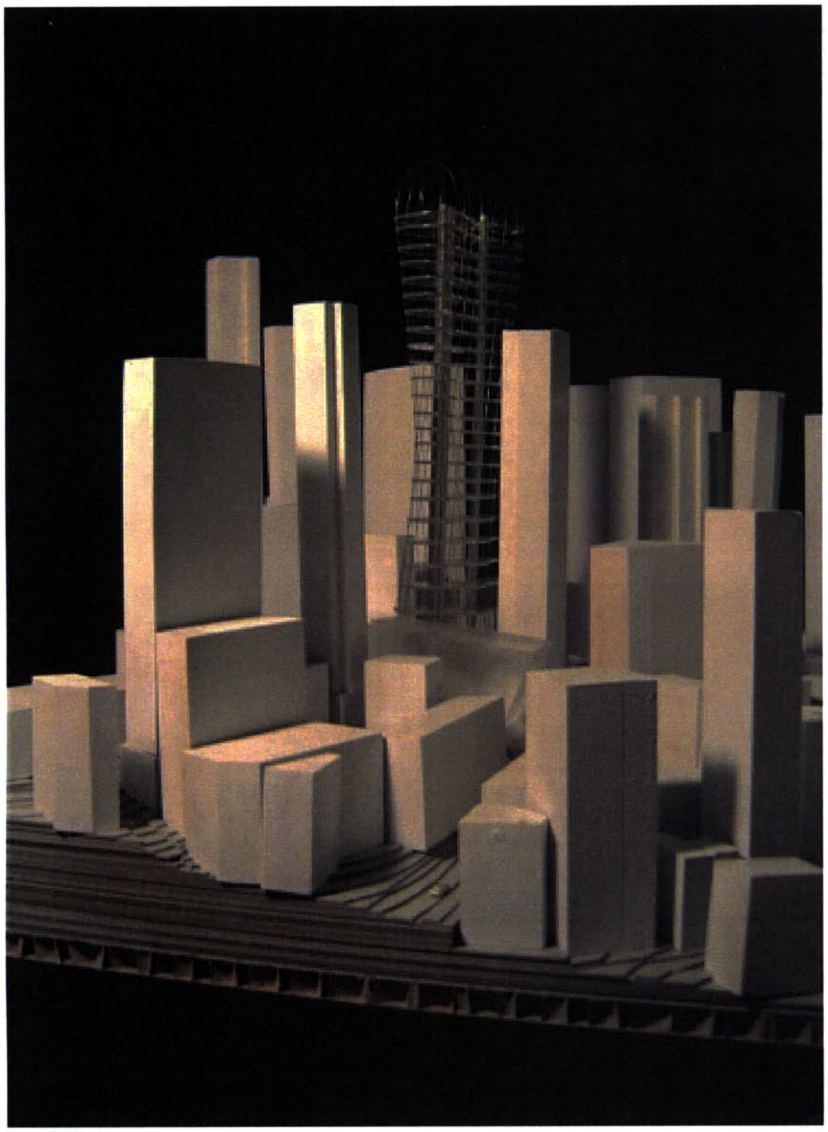
This model further represents the form of the tower using plastic and metal wires. Because of the material property of the composite strips, it is important that they are continuous at the top of the tower in order to eliminate any stress concentrations at connections. Holes at precise locations (drawn in CAD) are cut from the plastic floor plates using the lasercutter, and stainless steel wires are fed through these holes and over the top to illustrate the "head" form of the tower.

[5.46]

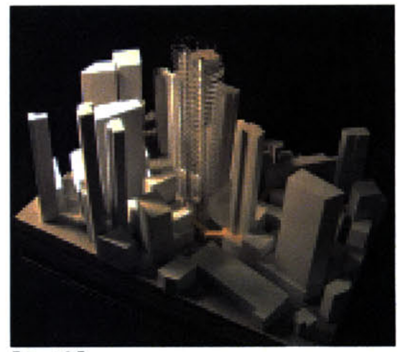


[5.47]





[5.48]



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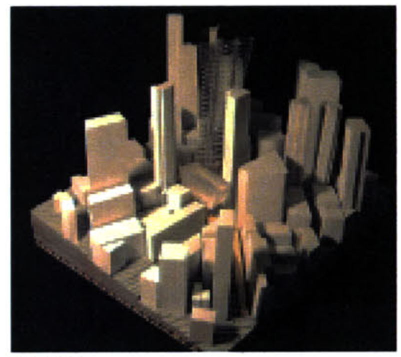
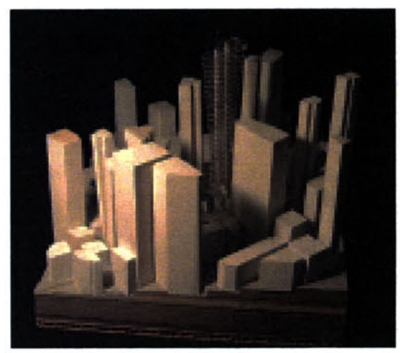


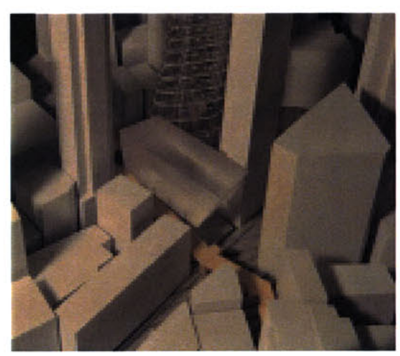
[5.50]



[5.51]

site model: wood, chip-board, plexiglas, stainless steel wires
scale: 1" = 32'

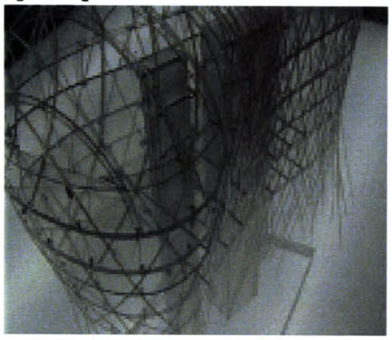
This site model enables a closer look at the context surrounding the tower. Because almost all buildings around the area are built right at the street edges, the streets are unusually narrow and crowded. While the models of cars on the streets allow one to understand the scale of the tower with respect to it surroundings, the model of the composite tower also suggests possible solutions to the urban problem at hand.



[5.52]

[5.56]

[5.47]



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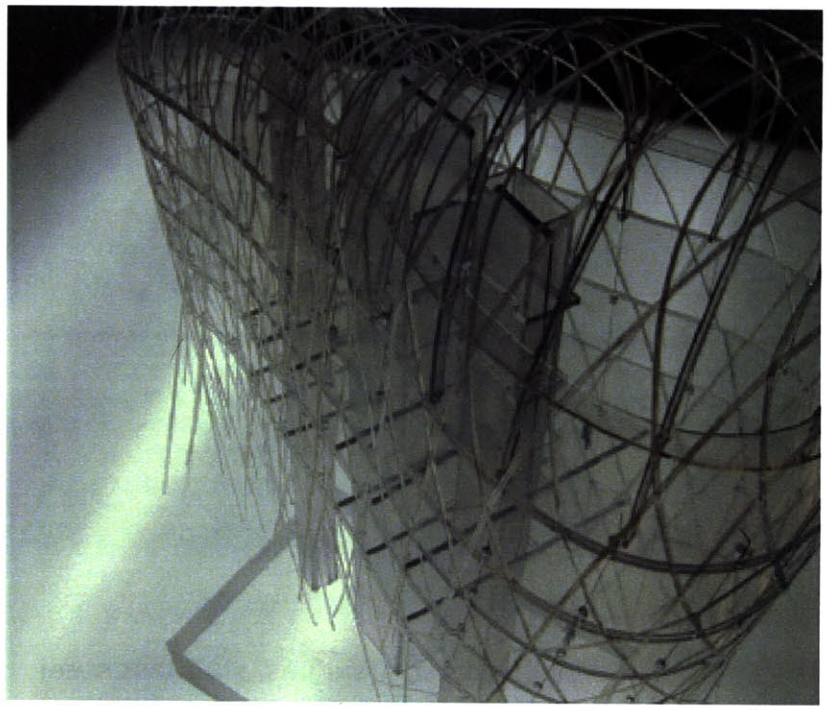

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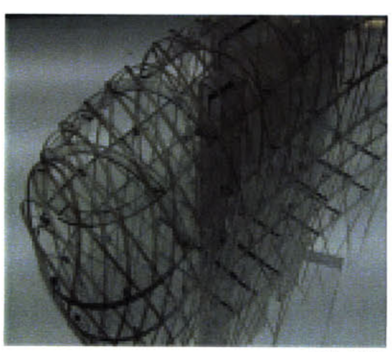
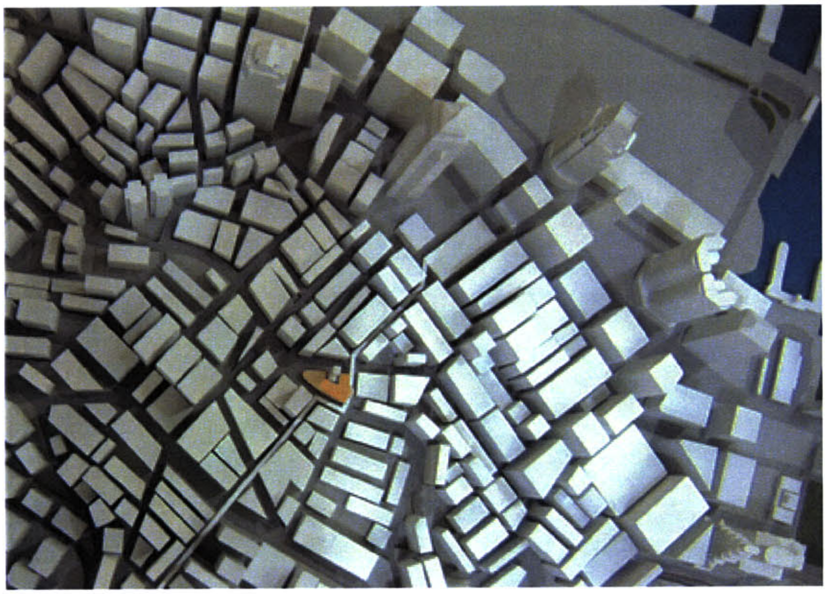


[5.55]

structural mesh model: plexiglas, plexiglas strips, stainless steel wires, aluminum tubes

scale: 1" = 8'

This eighth scale model demonstrates how the composite structural skin "drapes" over the concrete cores, as well as illustrates a few of the basic structural components, such as the floor slabs, cables and the steel cage. When looking inside the model, one can also begin to experience the spatial quality of the composite-woven interior.



[5.58] plan view

[5.59]

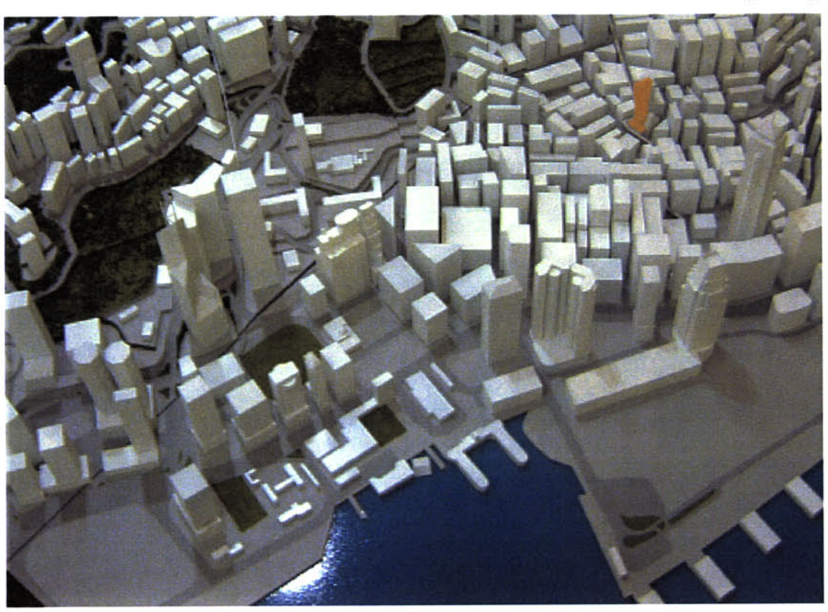
site model: plastic, wood, greens
scale: 1" = 150'

This site model allows one to understand the tower within the urban context of Central Hong Kong. Located at the nodal point between the Central Business District and Mid-levels residential area, the "sculptural" tower and podium provide a place for communal and gathering activities.

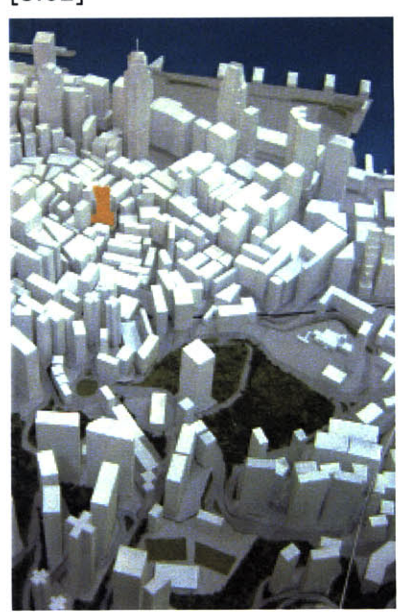
While the site model itself is made with conventional materials, the tower is produced by *Stratasys FDM2000* 3D printer. Despite its complex form, the model of tower can be easily created with the machine once it is digitally modeled.

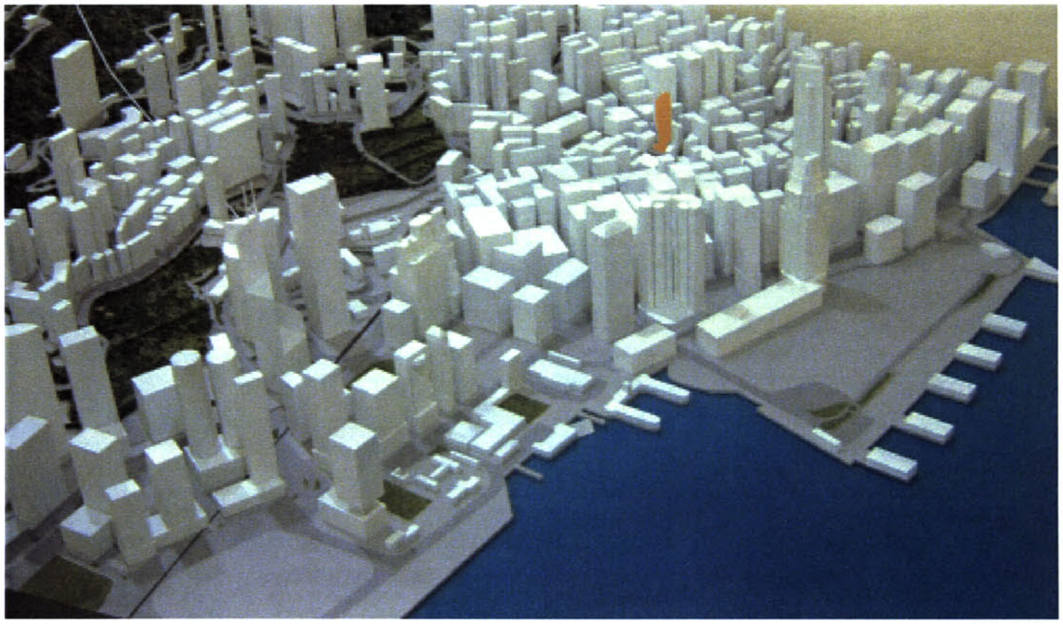
[5.60]

[5.61]



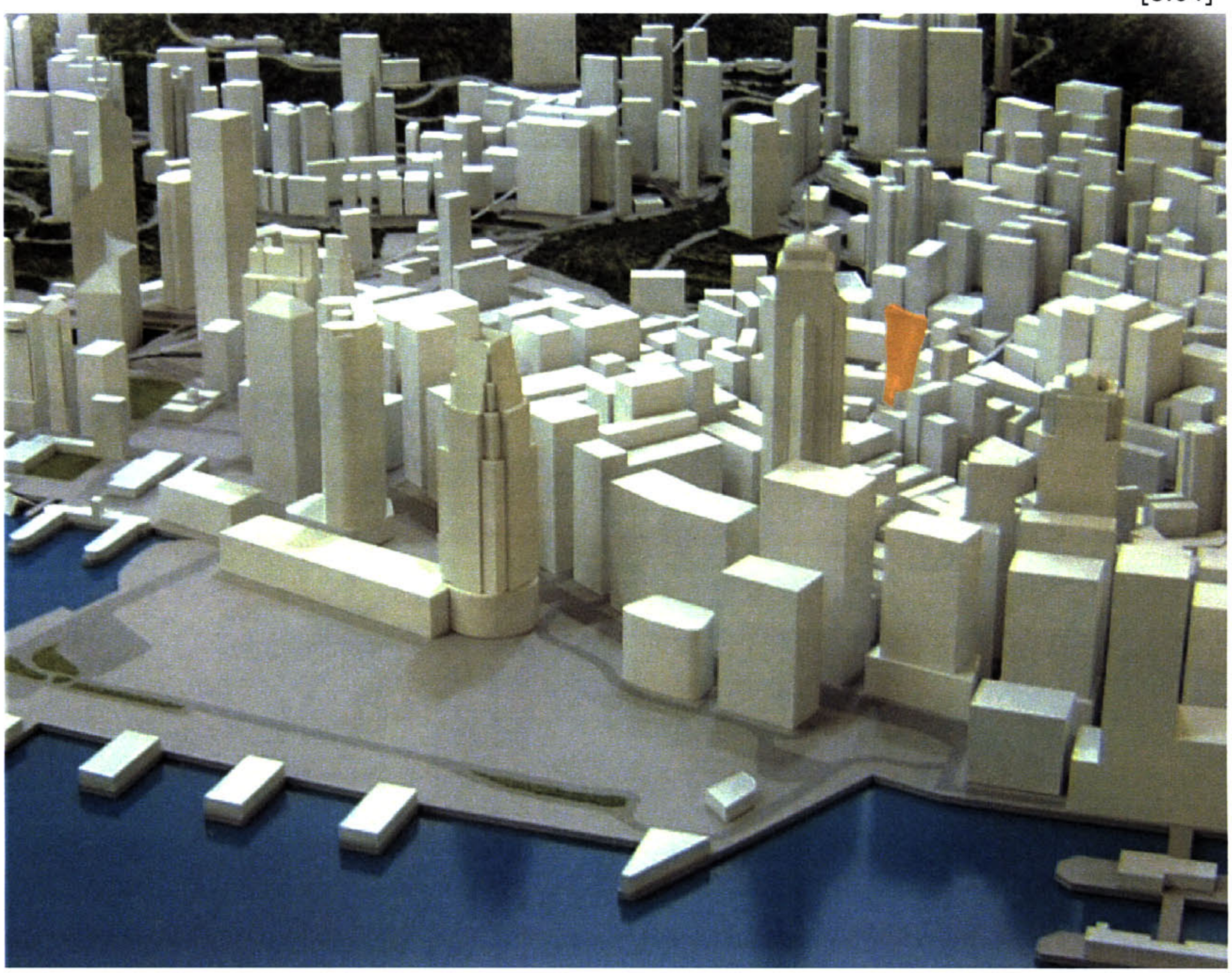
[5.62]





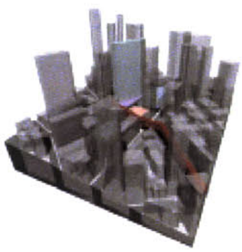
[5.63]

[5.64]



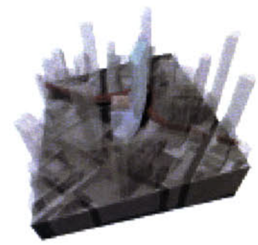
digital visualizations

As mentioned earlier in this section, digital models and physical models are developed simultaneously throughout the design process. The digital visualizations that are shown here begins with studies of the site, the massing and programmatic organization. A fly-through and a walk-through animation is then created to visualize the site in three-dimensions.



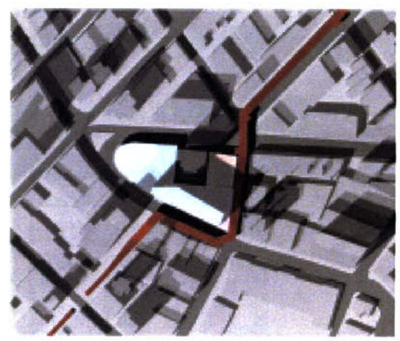
[5.65]

[5.66]



[5.67]

At first glance, these views of the model illustrate the density of constructions around the site. The translucent gray buildings are existing buildings and the existing elevator walkway cutting through the site is shown in red. There are three basic components shown in this model: the public podium block (for retail and gathering) is shown in light blue, parking facilities / hotel amenities block is shown in pink, and the private service apartment tower block is shown in light green. The two images of the site from a lower viewing angle further brings out the density of the numerous skyscrapers that are currently exisiting at the site. From this digital model, one is also able to identify possible "viewing corridors" around the site, a task not possible from simply looking at plans or sections.



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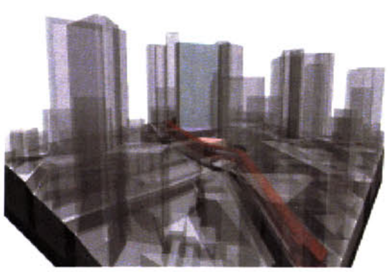
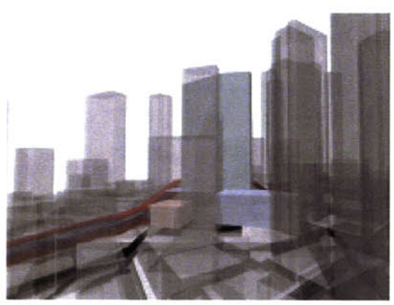


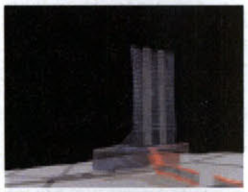
[5.69]



[5.70]

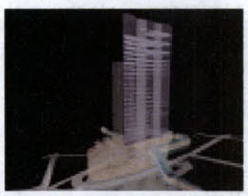
Modelling the design in digital form becomes a very crucial step when the tower begins to take shape. Numerous study models are created on the computer using AutoCAD 2000 and Mechanical Desktop 5 to design, represent and evaluate the surface structure of the tower.


[5.71]

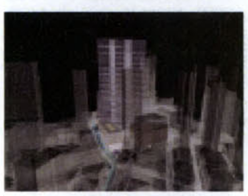

[5.72]


[5.73]


[5.74]


[5.75]


[5.76]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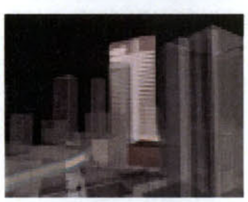
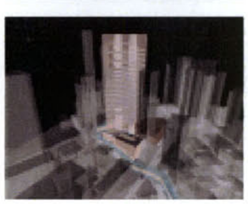
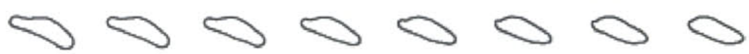

[5.78]

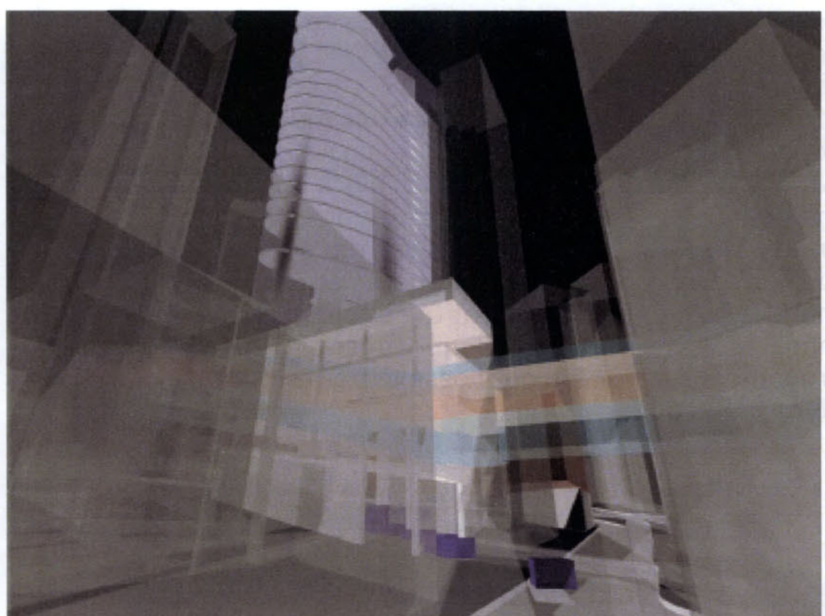

[5.79]

These digital iterations demonstrate the form-making process of the tower. Each study model is rendered in several different views, with or without the site context, in order for it to be evaluated. As mentioned earlier, the phyiscal model of the tower is modelled first in digital form, and then the shapes of the floor slabs are cut using the lasercutter.

The process of making the tower surface (in Mechanical Desktop 5) is as follows (from left to right):

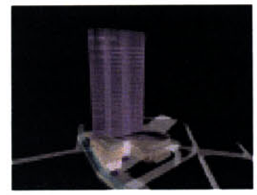
[5.80] floor shapes



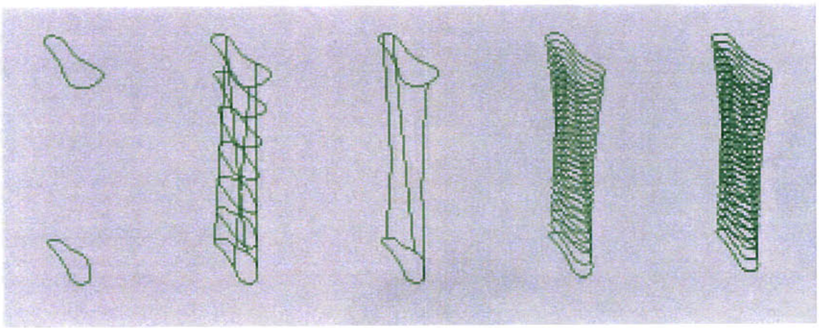

[5.81]

1. two splines of the desired forms of the floor plates are drawn and then offset to the full height of the tower
2. using the loft-u command, create the continuous surface between the two splines
3. create a solid from the surface using the surface/solid substraction command
4. using the planar surface, section the solid every floor height (e.g. 12 feet)
5. extrude each sectioned lines to create slabs

[5.83]



[5.82]



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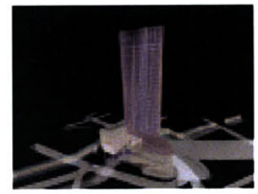
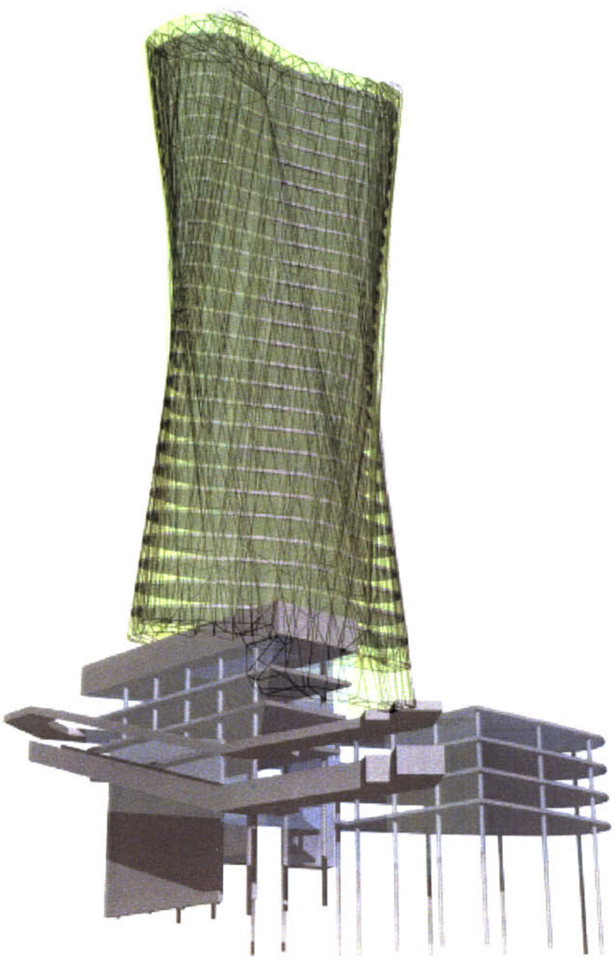
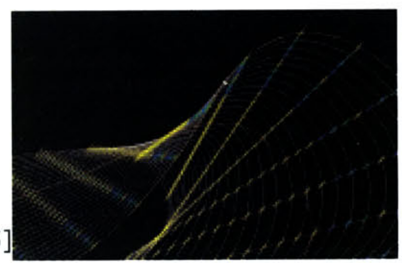
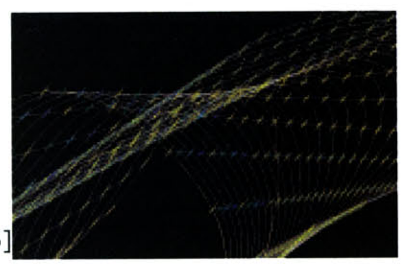




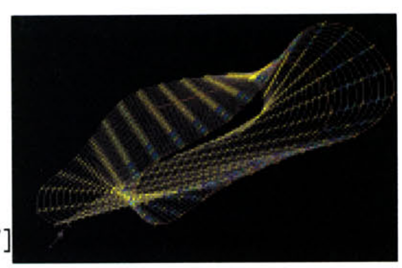
[5.85]



[5.86]

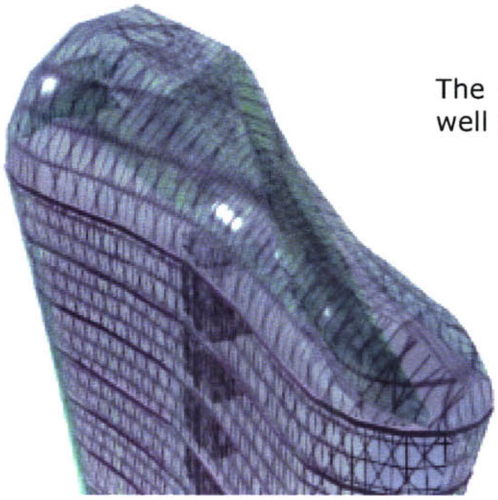


[5.87]



Screen snapshots of the surface shows the complexity of the surface structure.

[5.88]



[5.89]

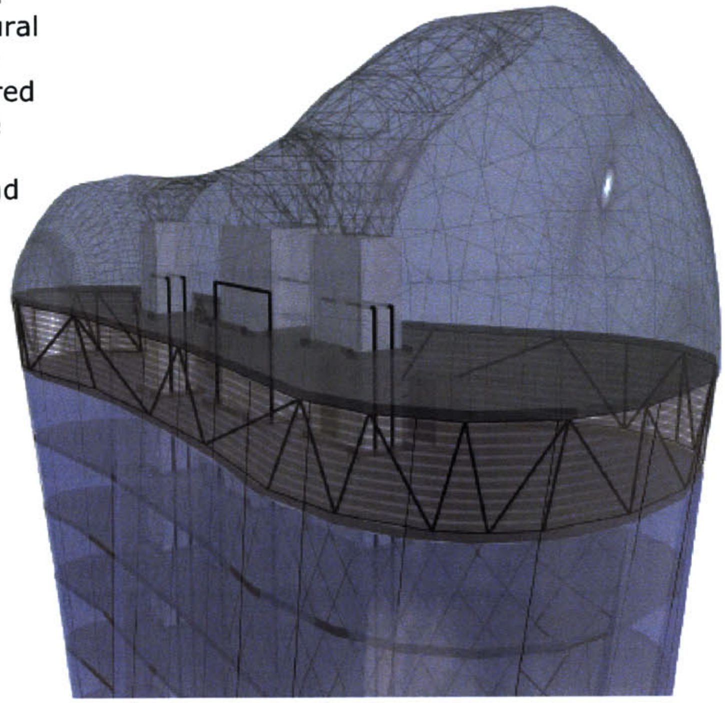
The digital model also allows one to explore the shape as well as the materiality of the "head" piece of the tower.

[5.90]

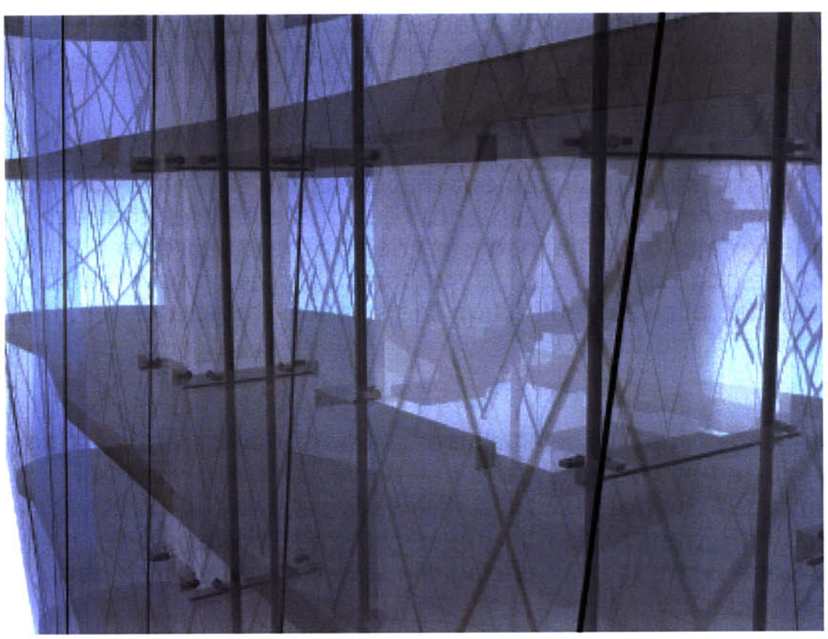
presentation renderings

Although the design idea is based on a very simple understanding of structures, the building system of the composite tower is not as straight-forward. A comprehension of the various structural components of the tower is therefore a fundamental requirement for one's understanding of the whole system.

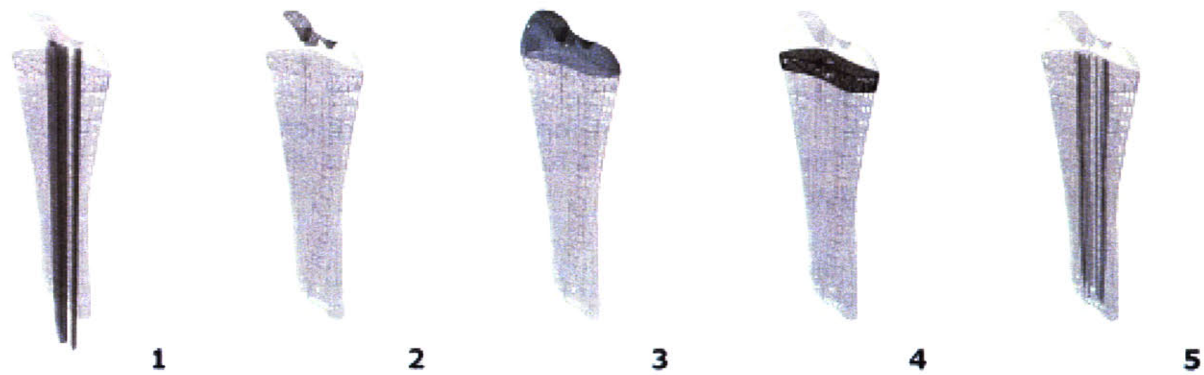
It is for this purpose that the use of digital models is most effective. First of all, different components of the structural system are modelled accurately on the computer and specific views are rendered after material qualities are applied. The two images below illustrates how the components at the top of the tower and at the cores come together.



[5.91] This closeup view of the top of tower shows structural assembly of the steel cage "cap", mushroom columns, transverse slabs, three concrete cores, and supporting cables.



[5.92] This perspective shows the interior component at the core of the tower. While each floor slab is supported by a set of composite cables that goes around the interior up to the cores, a number of roller/damping joints are fastened at the connection between the core and hole of the floor slab to allow for some flexibility.



[5.93]

Structural component diagrams:

1. Concrete cores with composite reinforcements
The three concrete cores (two for private use, one for service and fire) are cast on site, with the lowest four level being structurally connected to the podium floor plates. Extending far into the ground for foundation columns, these cores are to be positioned according to the specific load and forces acting on the tower to achieve maximum structural capacity. Only the top two transverse slabs and the mushroom columns are to be structurally connected to the core. None of the other floor slabs of the tower will be structurally connected to these cores; they are hung from the cores with composite woven cables.

2. Mushroom columns
The mushroom columns are structurally connected to the top of each of the three concrete cores. In order to support the massive steel cage "cap", the connection between the cores and the cap is extremely important. The form of the mushroom-shaped columns provide a larger surface area for the distribution of the loads from the steel cage "cap" to the cores. These could be made with high-strength steel sections.

3. Steel cage "cap"
The steel cage "cap" is the structural element that transfers the loads carried by the tension cables and composite mesh onto the concrete cores that act in compression. While a majority of the load is carried by the mushroom columns on the top, the edge of the "cap" is supported by the transverse slab below. Since the steel cap allows openings on the surface, it encloses a unique space on the top of the tower.

4. Transverse slab
Right below the steel cage "cap" is the thick transverse sandwich unit. Acting as a huge beam supported by the cores, the unit consists of two layers of thick composite reinforced concrete, supported by a truss system in between. The space enclosed by the transverse unit houses the mechanical room, as well as a counter-weight system for balancing the tower as it sways under high windloads or earthquakes.

[5.94]

5. Interior cables
Each floor slab is supported by a set of composite interior cables that are located around and tied to the concrete cores. Because each floor has its own set of cables, individual floors are not connected to one another. This support system therefore helps to prevent the collapse of the whole tower under cable failures.

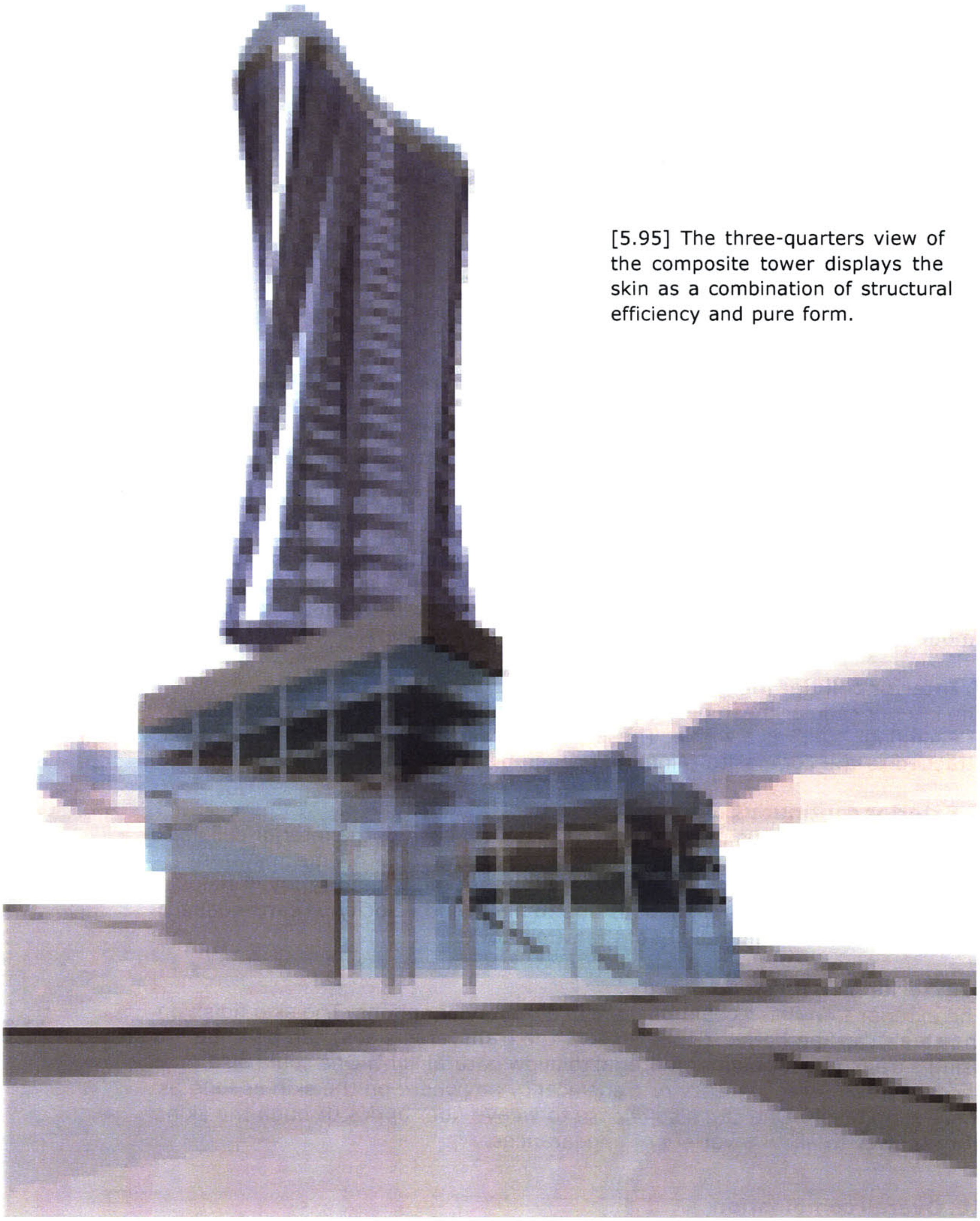
6. Exterior cables
Similar to the interior cables, each set of exterior cables provides the support for each of the floor slabs at the perimeter. This is particular important when some of the slabs have rather large cantilevers. The cable help to stablize the amount of deflection at these locations.

7. Interior cellular mesh
The interior cellular mesh between each of the floor slabs provides the rigidity of each floor "cell" as a whole. These composite meshes are woven and then attached to the composite reinforced concrete slabs on site.

8. Exterior continuous mesh
The exterior continuous meshes are connected to each of the interior cellular mesh and "drapes" from the steel cage "cap" on the top. This mesh system also helps to carry the dead load of the tower, but most importantly, it helps to carry the shear and torsion loads due to high wind velocity or earthquake conditions and to retain rigidity of the whole tower.

9. Exterior skin finish
The exterior skin finish could be done in a variety of options. The skin finish on the steel "cap" and other floors (except the transverse slabs) can be done using a transparent polymer material to allow natural light. One could also choose to have transparency or translucency anywhere on the skin as long as there is no mesh. One can also choose to weave fiber optics through the skin of the tower to allow a variety of appearances.

10. Overall combination



[5.95] The three-quarters view of the composite tower displays the skin as a combination of structural efficiency and pure form.

[6.0]

[overview]

[materials]

[boards]

[6.3]

[6.1]

"a Mardi Gras...?"

[6.2]

overview

Date :

Friday, December 19, 2000

Time :

1630 hrs

Location :

Advanced Visual Theatre (AVT) 7-431

Participants :

Peter Testa
Associate Professor of Architecture, MIT

William J. Mitchell
Dean, School of Architecture and Planning
Professor of Architecture and Media Arts and Sciences, MIT

Takehiko Nagakura
Associate Professor of Design and Computation, MIT

J. Kimo Griggs
Lecturer in Architecture, GSD, Harvard

Shi-Chang Wooh
Associate Professor of Civil and Environmental Engineering, MIT

Brian Carter
Chair, Dept. of Architecture, Univ. of Michigan

Tony McLaughlin
Buro Happold, New York

Blanca Lleo
Architect, Madrid

Alan Short
Dean, Faculty of Art and Design, DeMontfort University

materials :

website presentation

presentation boards [01 - 16]

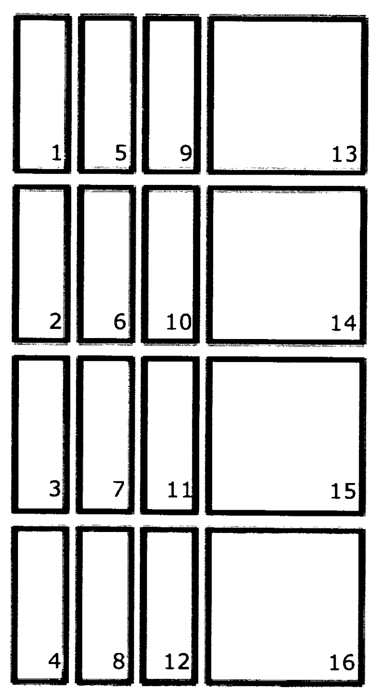
site model scale: 1″ = 150′

site model scale: 1″ = 32′

detail model scale: 1″ = 8′

study models include:
- surface studies
- tower iterations
- joint explorations
- carbon fiber and fiberglass panels

material samples include:
- reinforcement fabric samples
- pultruded section samples

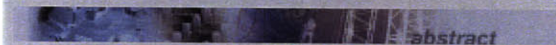


board index

Hyper-Light Architecture:
Composite Tower for Hong Kong

by Jeffrey Tsui

Advisor: Peter A. Testa, Associate Professor of Architecture, MIT
Reader: William J. Mitchell, Dean of school of architecture, MIT
Reader: Takehiko Nagakura, Associate Professor of Architecture, MIT
Reader: Kimo Griggs, Lecturer of Architecture, GSD, Harvard
Consultant: Shi-Chang Wooh, Associate Professor of Civil Engineering, MIT
Consultant: Natalia Cardelino, Ove Arups and Partners, Cambridge, Massachusetts



The initial concept of the thesis begins with an interest in exploring the materiality, manufacturing and aesthetics of **modern product design** and its relationship with architecture and space. The approach to problem begins from an exploration of specific materials that are commonly used in other design and manufacturing fields but currently underutilized in the building construction industry.

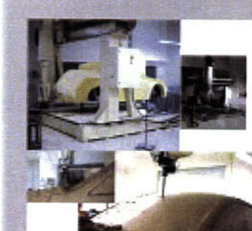
The IMAC is a typical example of modern product design where pure form does not have to be dictated by its functionality.

A garbage bin is in itself a monocoque structure where its continuous "skin" also serves as supporting extra loads.

The Central district of Hong Kong is crowded with sky-scapers and high-rise buildings.

The thesis is an investigation of exploiting **composite materials in developing a structural system** for buildings and construction. Specific properties of composites, various connection techniques as well as different construction/fabrication methods involved are essential issues that are explored throughout the design process. The project targets in creating a new typology and aesthetics in **vertical building systems** that takes advantage of the specific structural characteristics of these materials. Utilizing the characteristics of high-density site conditions such as the **Central district in Hong Kong** and through an application of a sensible programmatic organization, the project serves as a demonstration of the design within a realistic environment as well as pragmatic constraints.

Bauhaus' design collections of metal, fabric, wood and glass serves as an early example of intergrating architecture with product design.



C-tek's 5 axis milling machine allows large prototype to be made. In this series of images, a whole car is created off a block of clay as one whole piece.

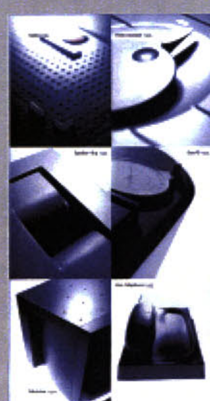
board 01

The exploration of architecture begins with an examination of the **characteristics of composites**: what its strengths and weaknesses are. The form of architecture is about providing an energy-sensitive environment within an efficient skin/structural system, at the same time maximizing usable and flexible floor area in a high-density context. The unique appearance of the building also optimizes the strengths of the composite materials; a similar form would be difficult or expensive to achieve when using other conventional materials and methods.

Kovac/Malone's Ikon Tower is finished in concrete, steel and carbon fiber. It is linked by a neural network of optic fibers that relays information to its central computer systems, which then feeds the building's artifical intelligence.

Numerous recent buildings by Frank O. Gehry and Associates introduce curving elements. Although advanced computer-aided design and manufacturing techniques are utilized, a lot of the materials being used are still quite conventional.

Christian de Portzamparc's glistering glass facade of the LVMH Tower in Manhattan gives a clue to the glamorous fashion products that the company is known for.



Philip starck's products and buildings are often embedded with sensuous curves.

The BMW pavilion uses CAD/CAM technologies to create two organic forms of water droplets with conventional steel ribs as structure.

board 02

The term composite refers to a **homogeneous material made up of two individual components whose combined physical strength exceeds the properties of either of them individually.**

Different types of composites include:

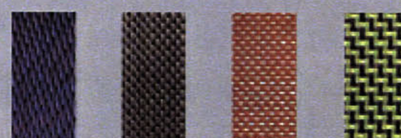
1. timber/wood composite
2. reinforced concrete
3. fiber-reinforced plastic

One kind of composites that is explored in the thesis is known as **fiber-reinforced plastic**, which consists of a fibrous reinforcing network embedded in the cured resin matrix. The thermosetting type resin is a plastic that cures from a liquid to a solid through a chemical reaction of its two components.

More specificaly, the types of composites that is utilized in this project includes the following:

1. composite reinforced concrete core
2. carbon fiber wrapping of structural members
3. carbon fiber woven cables
4. pultruded structural mesh (for skin)
5. pultruded structural mesh (for concrete reinforcement)

Examples of fiber reinforcement: carbon fiber, glass, Kevlar



MOLDING: Molding is the process of constructing a part within a mold. Typically, precut reinforcement is placed one layer at a time into the mold and saturated with resin. When the part has achieved the desired thickness and orientation, it is left to cure. When it is demolded, it will have the exact shape of the mold surface.

LAMINATING: Laminating originally referred to applying a thin protective coating of resin and reinforcement over a surface such as wood. The term's use has broadened to include virtually any finished composite part, molded or otherwise.

CASTING: Casting refers to pouring a large mass of resin into a cavity. The cavity can be a mold when casting parts, or it can be the backside filler for a tool when making the mold itself. Specialized casting resins are necessary which generate less heat during their cure and thus create less distortion in the final part. Fibrous fillers can be added as needed to strengthen the casting.

SCULPTING: Sculpting is usually accomplished by carving a shape out of polyurethane foam and then laminating the surface. This can be done to create a plug for the molding process, or to shape a finished part in the case of moldless construction.

Carbon fiber model precedures:

1. prepare mold, spray with Teflon or similar release agents
2. cut carbon fiber fabric in the appropriate sizes
3. mix up epoxy resin with the appropriate combination ratios
4. apply mixed resin to the underside of the fabric with a brush
5. lay wet fabric on top of the mold and apply more resin to the top of the fabric
6. use a roller to eliminate air voids
7. apply another layer of fabric if necessary and repeat adding resin to the fabric
8. let the fabric cure for 3-4 days
9. apply addition paint or coating if necessary

board 03

Fiberglass model is made with similar procedures.

Pultrusion is a manufacturing process for producing continuous lengths of reinforced plastic structural shapes with constant cross-sections.

Raw materials are a liquid resin mixture (containing resin, fillers and specialized additives) and flexible textile reinforcing fibers. The process involves pulling these raw materials (rather than pushing, as is the case in extrusion) through a heated steel forming die using a continuous pulling device. The reinforcement materials are in continuous forms such as rolls of fiberglass mat and doffs of fiberglass roving. As the reinforcements are saturated with the resin mixture ("wet-out") in the resin bath and pulled through the die, the gelation, or hardening, of the resin is initiated by the heat from the die and a rigid, cured profile is formed that corresponds to the shape of the die.

Other applications of composites include:

Aircraft: Military, homebuilt, experimental, and commercial aircraft have used composite materials for years.

Automotive: Buses, trucks, and bicycles have found increasing use for composites. Race cars chassis have been made with composite for some time now, as well as consumer vehicles are beginning to use composites for interiors and framework.

Industrial: The unique corrosion resistance, strength-to-weight, electrical conductivity, and formability of composites lend themselves to an increasing variety of industrial applications.

Marine: Boats, jet skis, paddles, canoes, kayaks, and buoys are a wide variety of examples where the ability to withstand prolonged exposure to water, salt, gasoline, chlorine, and ultraviolet light is critical.

Sports Equipment: Skis, snowboards, tennis rackets, surfboards, golf shafts… are mostly made of composites.

board 04

The thesis project will initially be realized on a site that is located in the heart of the **Central district in Hong Kong** Special Administrative Region, Peoples Republic of China. Situated on southeast coast of China, Hong Kong has become one of the world's most densely populated cities. Also known as the capital of Hong Kong, the Central district of Hong Kong is the location for the **central business district, high-end residential developments, major hotels, restaurants** and shopping, as well as the busiest node of public transportation systems. Aside from being situated close to the seismic region, Hong Kong also has high **windloads** during the humid summer seasons due to frequency typhoons.

From looking at the skyline of Hong Kong from the Victoria Harbor, one can then realize the abundance of high-rise buildings. In fact, the city is so dense that the width of a typical site in Central Hong Kong could only as long as a car's length.

The **escalator system** provides a north-south pedestrian link between the Mid-levels and Central. It is 800m long and climbs to a height of 135m. The site of the project is located almost at the mid-point of the escalator, where the walkway formed a "**notch**" around the site. Most of the surrounding buildings are old mid-rise residential units, except for a newly constructed office tower. This office tower will be kept for the purpose of the project. This elevated walkway, extending over 1km into the pedestrian system with overpasses linking up a number of key commercial buildings within the Central Business District sitting on reclaimed land.

The existing 25-story office building at the north of the site is to be kept as to illustrate of a less-than-ideal site condition common in high-density cities.

board 05

Existing apartments and stores are within very close proximity to the elevated structure and are visible to any pass-byers. Issues concerning the arrangement of the private and public domains are thus important during the form making process as well as the organization of the various programmatic elements within the complex.

Images of Hong Kong showing the how we live, work and play.

board 06

design

The design of the building is generated through an integrated process of the following design directions:

1. **the dynamism of the existing site:**
   the escalator, the existing office tower on the north, the sloping condition

2. **the programmatic organization:**
   public/private sectors for various activities that could be held within the complex

3. **the properties and characteristics of the material:**
   design optimizes the structural and spatial flexibility

The main challenge of the design is to create a composite skin structural that carries the tensile loads of the building, and transfer the loads to a more convention concrete core system that carries the compressive loads. A similar idea of such a structure is evident in a jellyfish or a lantern.

There are two approaches to the design of the structural skin: the **panel system** (similar to a lot of Frank Gehry's buildings, such as the "Fred and Ginger Building") and the **mesh system** (Richard Deacon's wooden chair).

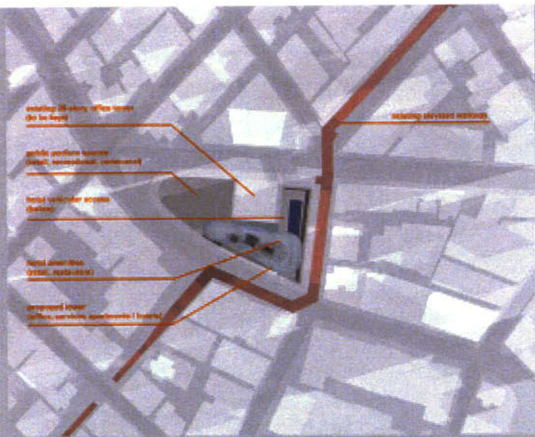
Buckminster Fuller's Suspended Tower is an example of a circular building that is supported purely by cables.

Charles James diagram of a dress shows the structure and layering techniques of fabricating the piece of garment.

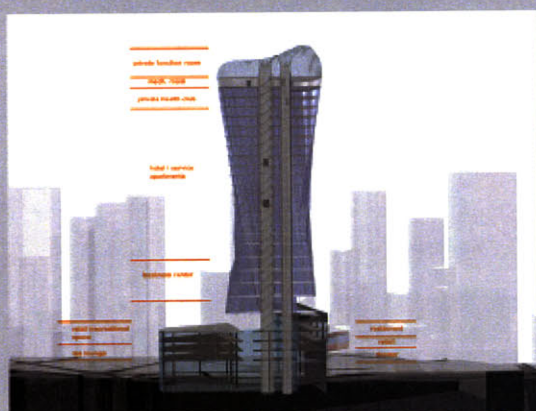
Boston's 64-room 15 Beacon hotel, for example, provides more of an unique staying experience than the usually Hyatt or the Four Seasons.

Because of the location of the site and existing programmatic nature of the neighborhood, a **mixed-use and adaptive program** will be adopted. The bottom three podium floors will serve as a public space that could be utilized throughout the day. The first two stories consist of a combination of furniture galleries and boutiques and a tea lounge. The top two stories consist of a bar/restaurant and a "deliver center" which serves as a **nodal community area**, convenient because of the location of the site. There is also sufficient open spaces which serves as a gathering, communal and recreational area. The idea is to create a series of spaces that can be flexible for efficient use in terms of varies times of the day. Located above the public domain will be a tower structure housing **hotel suites/service apartments, work spaces, a private health club and a private function space/library/wine bar at the top.** These service apartments aim at young professionals who enjoy the freedom of living alone in an area of nightlife and activities.

panel 07



The site plan illustrates the massing components and accessibility within the site.



Sectional perspectives demonstrates the mixed-use programmatic organization within the complex.

A series of preliminary **structural calcalations** is performed to allow a better understanding of the load magnitude of the composite tower:

Density of lightweight concrete:
= 1750 kg/cu. m
= 1750 *(2.2/39.373)
= 0.06310 lb/cu. in.
= 109.0 lb/cu. ft.

Total volume of slabs = 68120 cu. ft.
Total surface area of tower = 80210 sq. ft.

Assuming only 20% of the total surface area is to be covered with the structural mesh

Total area of mesh surface = 80210 * (0.20)
= 16040 sq. ft.
= 27720000 sq. in.

Density of carbon fiber = 1.8 g/cu. cm.
= 1.8 / (2.543)
= 0.1098 g/cu. in.

Total weight of the exterior structural mesh
= 27720000 * 0.1098
= 3045000 g
= 6699 lb
= 3.35 tons (negligible)

Total weight of all floor slabs
= 67120 * 109.0
= 7320000 lb
= 3660 tons

With a safety factor of 2.0, the total dead load
= 3660 tons * 2.0
= 7316 tons
= 14600000 lbs

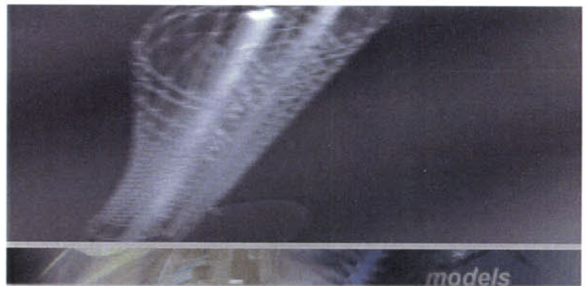
Tensile strength of carbon fiber composite
= 330 ksi

Load required = Strength * Area

Area = 14600000 / 330000
= 44.3 in2

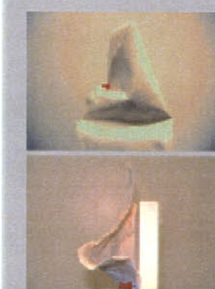
Assuming the number of vertical tensile members to be 24 per floor, each member will have a minimum cross-sectional area of 1.85 sq. in.

panel 08



massing model: chip board and wood
scale: 1/32" = 1'

This is a simple massing model illustrating the basic programmatic organizations. Contours of the site is cut using the laser-cutter, and the massing of the buildings and the existing elevated escalator are both made in wood.



fabric model: canvas, liquitex, wood
scale: not to scale

This is a simple study models investigating the properties of a canvas fabric. The idea is to use the fabric as a skin that is supported by a wooden "core" and then the canvas is hardened with liquitex. This procedure of fabricating the "skin" is similar to the actual process of apply resin to composite fabrics.

floor plate model: chipboard, wood
scale: 1/32" = 1'

This chipboard model investigates the shape of floor plates on different elevations of the tower. A 3D digital surface model is created on the computer by lofting between the desired floor plates on 3 different levels. A planar surface is then used to section the surface every 10 feet, creating the basic framework of the tower.

surface model: plexiglas
scale: not to scale

This series of models introduces the use of plexiglas and heatgun to make compounded curves. The idea is that the monocoque structure of the plexiglas models represent a similar skin/structure system of the tower. This technique of making compound-curved objects are later used for molds for creating fiberglass and carbon fiber models.

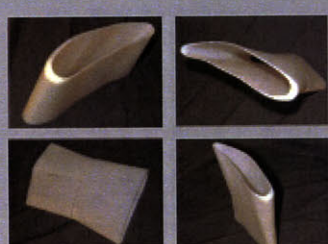
panel 09

surface model: plexiglas
scale: 1/32" = 1'

This model illustrates the different possibilities for surface structures. A piece of plexiglas is cut and placed on the chipboard model and is then heated with a heatgun. After heating for several minutes, the plex- begins to soften and take the form of the chipboard mold.

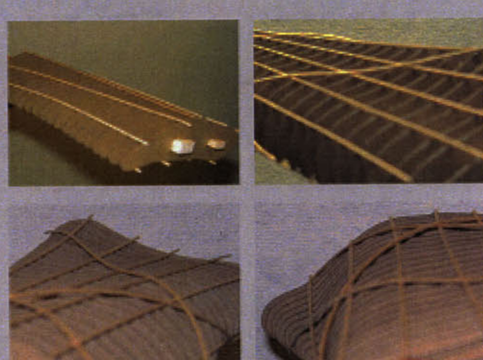
joint model: metal screws, plexiglas
scale: not to scale

These simple joint models illustrate the problem of connections with composite structural panels. Any holes that are created from a mechanical joint introduce hugh stress concentrations around the area where an absence of reinforcing materials highly reduces the strength of the panel.



surface model: plastic
scale: 1/32" = 1'

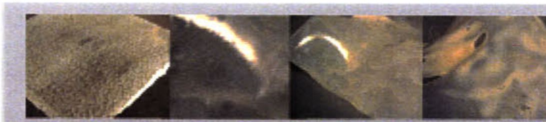
Produced by the *StrataSys FDM2000* 3D printer, this model shows the "shell" of the skin as a monocoque piece. One can then begin to experience the undulating surface when seen through the hollow object.

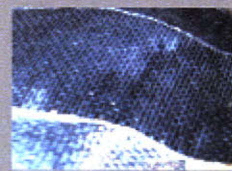


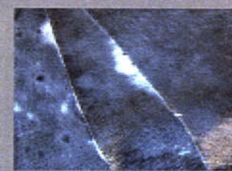
tower structure model: chipboard, wood
scale: 1/32" = 1'

These model is built upon the tower form studies and structural strips are added to bring out the compound curved skin surface. The floor slabs could be seen as ribs supported by the core and the vertical and diagonal strips are the substructure for the skin to rest on. The combination of the wooden strips and the horizontal plane also suggest a grid system of how the skin panels are shaped.

panel 10



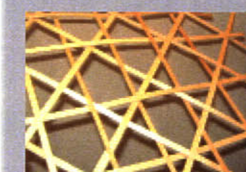


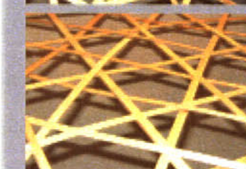


composite model: carbon fiber / fiberglass, epoxy, plexiglas mold
scale: not to scale

As mentioned earlier, an obvious problem with structural composite panels is that any mechanical joint introduces stress concentrations around the hole. Although one solution is to add multiple layer of various directions to provide more homogenous materials to distribute the stress, the same could not be applied to large opening such as windows. One could still use the material for a curtain wall construction supported by another substructure, but that would defeat the purpose for using the material.

This carbon fiber panel model is an attempt to overlay several layers of uni-directional fabric in different directions to create a more homogenous material that has tensile strength in multiple directions.





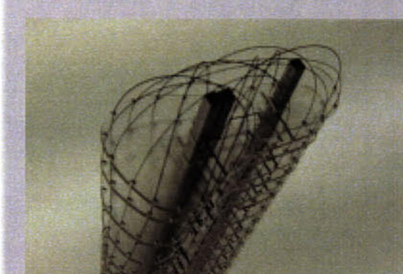
structural mesh model: bass wood strips
scale: not to scale

This model represents the structural skin mesh made with pultruded composite strips. Strips of wood are woven to form a mesh that is structurally self-supporting. No adhesive is needed except at where two layers of strips (representing the primary vertical elements) are glued together. The pattern of the mesh comes from that of the carbon fiber fabric. Vertical strips are needed for the gravity loads, and the diagonal strip are needed for lateral reinforcements.

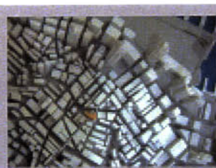
tower structure model: plexiglas, brass tubes, stainless steel wires

scale: 1" = 32'

This model further represents the form of the tower using plastic and metal wires. Because of the material property of the composite strips, they will have to be continuous at the top of the tower in order to eliminate any stress concentrations at connections. Holes at precise locations are cut from the plastic floor plates using the lasercutter, and stainless steel wires are fed over the top and through these holes to illustrate the "head" form of the tower.



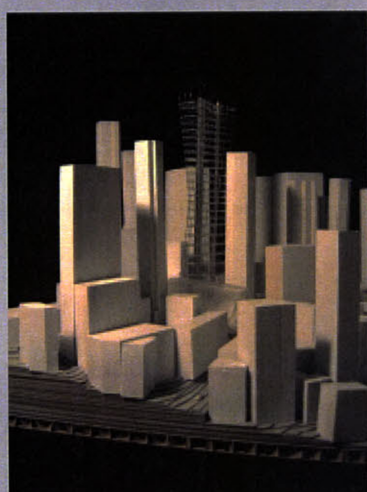
panel 11



This site model allows one to understand the tower within the urban context of Central Hong Kong. Located at the nodal point between the Central Business District and Mid-levels residences, the "sculptural" tower and podium provide a place for communal and gathering activites.

site model: plastic, wood, greens

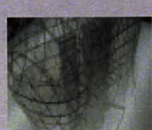
scale: 1" = 150'



site model: wood, chip-board, plexiglas stainless steel wires

scale: 1" = 32'

This site model enables a closer look at the context surrounding the tower. Because almost all buildings around the area are built right at the street edges, the streets are unusually narrow and crowded. While the models of cars on the streets allow one to understand the scale of the tower with respect to it surroundings, the model of the composite tower also suggests possible solutions to the urban problem at hand.



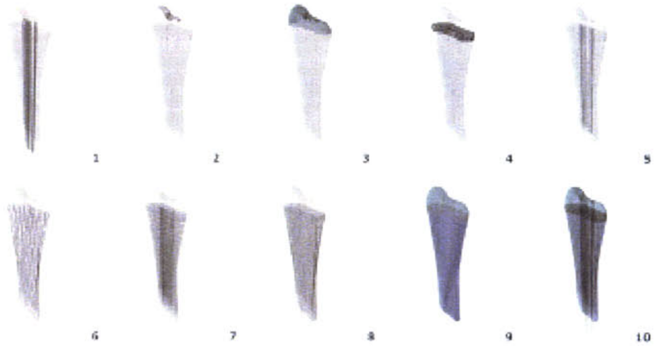
This eighth scale model illustrates how the composite structural skin "drapes" on top of the concrete cores, as well as a few of the basic structural components, like floor slabs, cables and steel cage. One can also begin to experience the spatial quality of the composite-enclosed interior.

structural mesh model: plexiglas, plexiglas strips, stainless steel wires, aluminum tubes

scale: 1" = 8'

panel 12

Structural component diagrams:



1. Concrete cores with composite reinforcements
[illegible]

2. Mushroom columns
[illegible]

3. Steel cage "cap"
[illegible]

4. Transverse slab
[illegible]

5. Interior cables
[illegible]

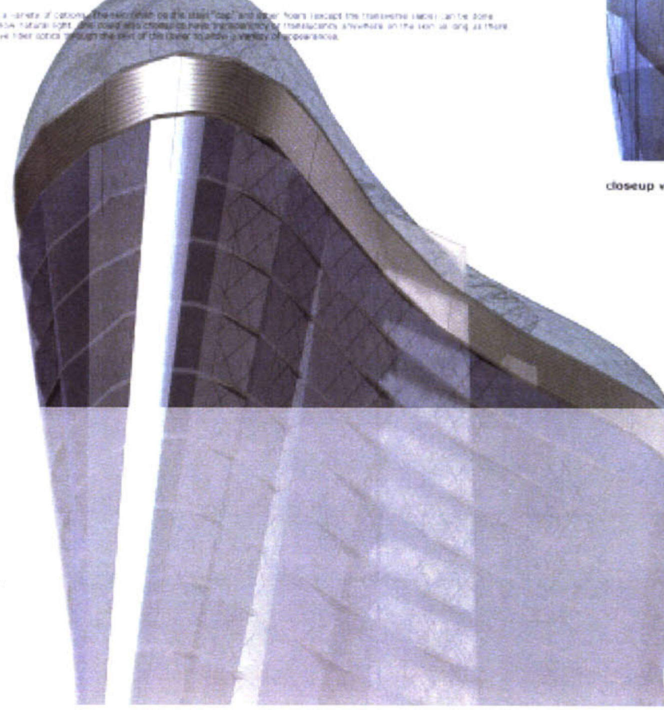
6. Exterior cables
[illegible]

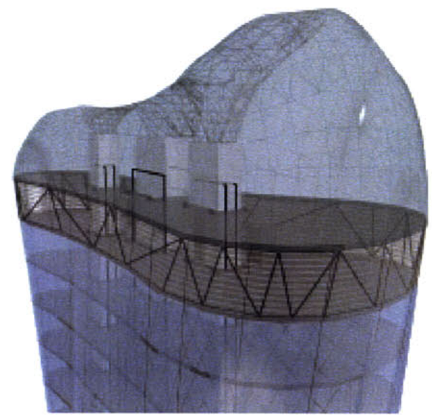
7. Interior cellular mesh
[illegible]

8. Exterior continuous mesh
[illegible]

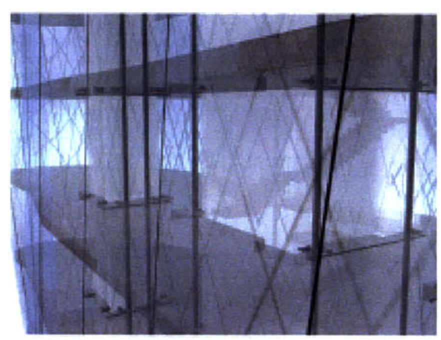
9. Exterior skin finish
[illegible]

10. Overall combination





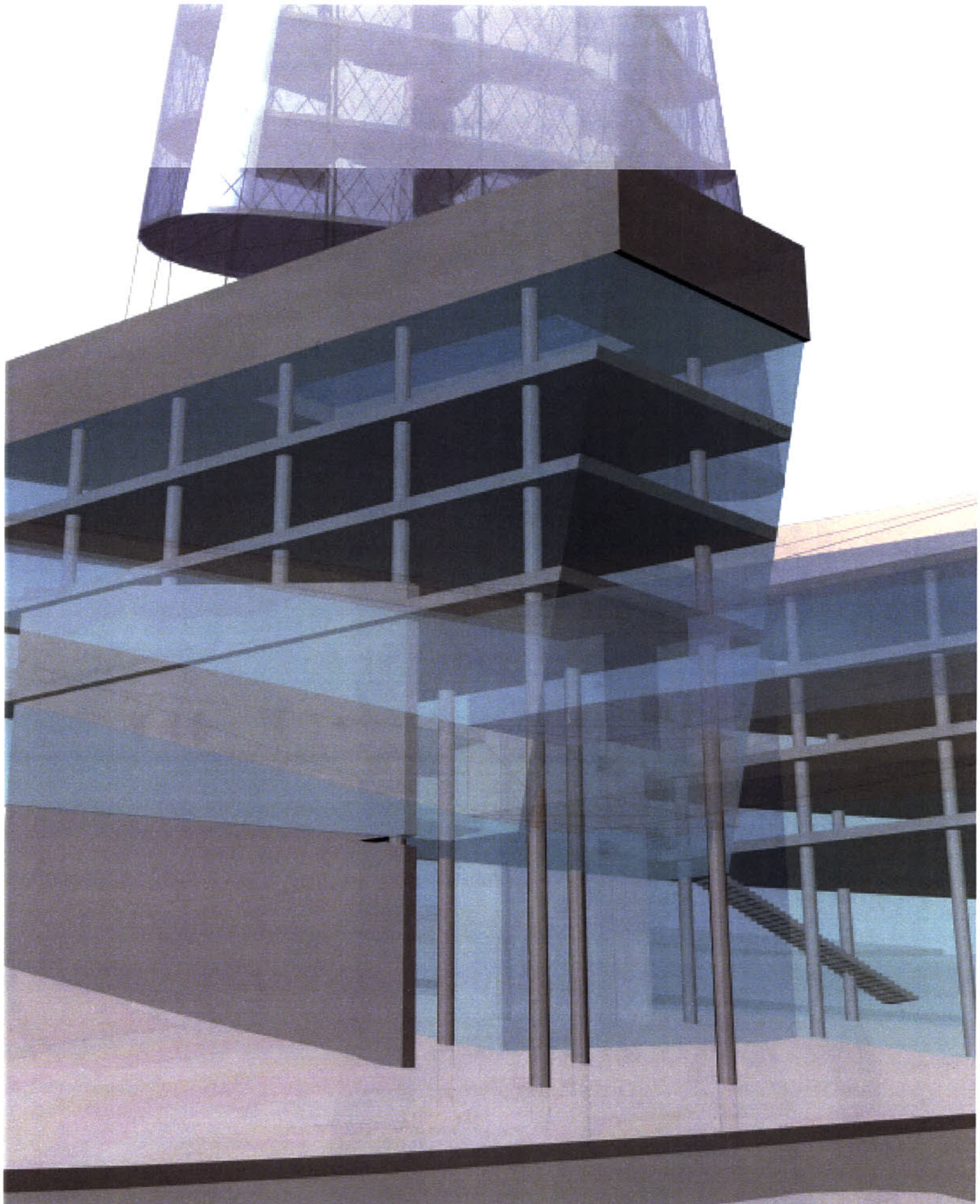
view of the top section of the tower

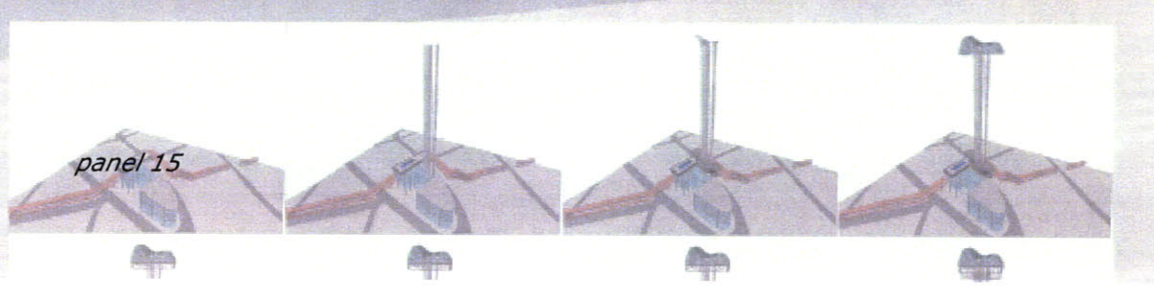


closeup view of core

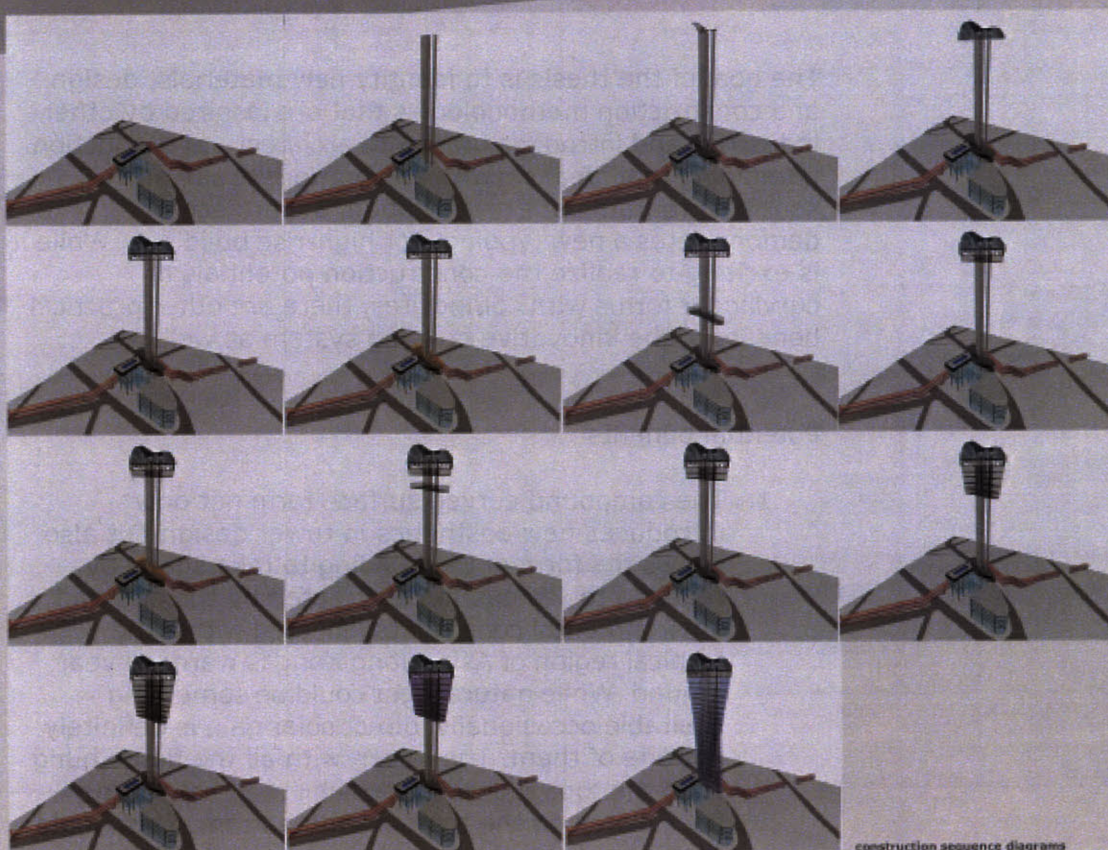
panel 13

panel 14





panel 15



construction sequence diagrams

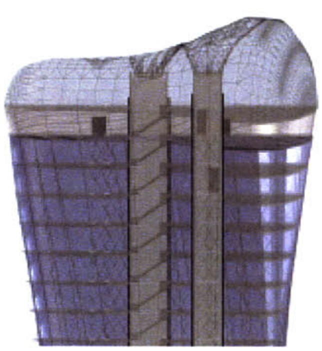
1. pour concrete cores
2. wrap the exterior of concrete cores with carbon fiber reinforcement
3. pre-fabricate composite-reinforced concrete slabs
4. insert all portions of each slab from top down through cores and join individual floors on-site
5. build mushroom column on top of each concrete core
6. cast top transverse slab and add on steel cage cap supported by mushroom column and slab
7. attach interior composite mesh with the top slab from the stack
8. pull the top slab up
9. fasten slab with carbon fiber woven cables from core
10. repeat for every floor from the top down
11. tie interior composite cell mesh at each floor edge to the exterior skin structural mesh
12. attach pre-fabricated skin panels for enclosure and tanaparent polymer for openings

conclusion

The goal of the thesis is to identify new materials, design and construction methodologies that are inspired by other industries and introduce them into architectural production. Combining that idealism with an appropriate site and a sensible programmatic organization, the project demonstrates a new typology for high-rise buildings. While it is exciting to realize the construction potentials of curvilinear forms with composites, there are other practical benefits of the innovative building system as well.

Potential benefits

1. The compound curved surface form not only introduces new aesthetics in tower design but also allows the form of the building to take shape by reacting to various forces created by the site and environmental constraints. Located within the tropical region of Asia, Hong Kong is warm all year around. While natural light could be something desirable occasionally, direct solar gain is definitely not one of them. The tower, with all the floors hung from the top, allows the possibility to have larger floor plates on the top than the bottom. This would provide natural shading elements for all the floors without any extra shading devices. This idea is also favored by the high-density urban characteristics of Hong Kong, or downtowns of other metropolitan cities, where the street levels are extremely crowded. Instead of taking up the maximum ground space in the lower levels, the tower allows a smaller floor plate on the bottom, expands as it goes up while maintaining the same usable square footage. In this design, for example, the form of the tower "tapers up" on the northern side where an existing 25-story office building is located. However, the floors of the tower are able to expand on the western side and around the office tower as it goes up.



[7.1] This section shows the expansion of floor slabs on the top of the composite tower.

2. The form of the tower is also more structurally efficient for high wind loads and seismic activities. The idea is that the rigid cores are planted deeply into the foundation, while all the floors are hung from the top. Therefore they are flexible enough not to collapse during earthquakes. Moreover, the composite tower is the strongest at the top, as opposed to a convention tower where the top is always the weakest and is subjected to deflections. Since wind load increases exponentially with respect to height, this structural system is very effective in locations with high wind loads such as Hong Kong.

3. While much of the dead load of the tower is carried by the tensile, fiber-woven cables, the exterior composite structural mesh doubles up to resist the shear and torsion. This enables the interior spaces to be free of columns and shear walls, thus allowing unlimited flexibility for different uses.

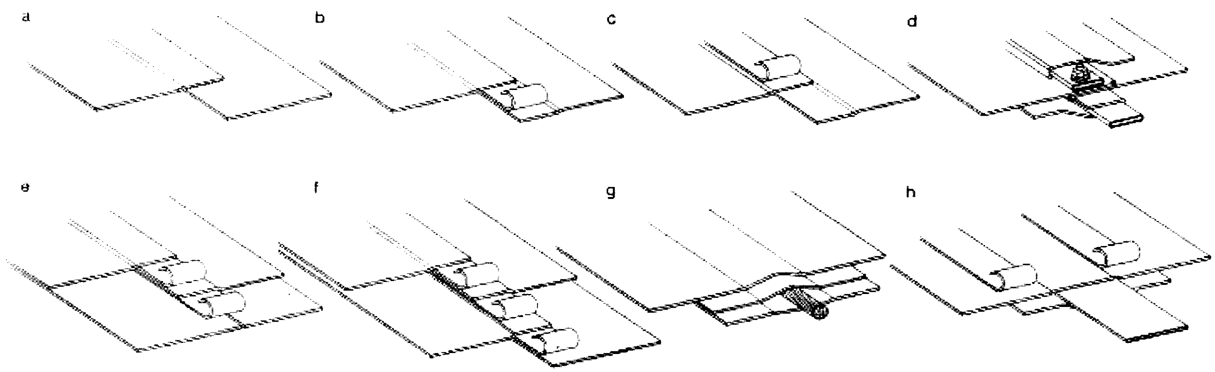
4. Most of the components are pre-fabricated. In addition, because the composites are so much lighter compared to conventional materials, the assembly time required on-site could be reduced. As mentioned earlier in the *site* section, a day's interest for a site in any major city could be a large sum of money. A developer could save millions of dollars if the construction time is cut down by half.

Although the project has succeeded in developing a new fundamental way of approaching the architectural design of high-rise construction, there are a few key issues that have not been fully tackled due to time constraints.

1. connections

Because there is not a precedent for such a building system, conventional connections and details are not be applicable in this design. One therefore needs to look at other manufacturing industries and techniques in order to rethink how these details could be resolved. Prof. John Fernandez from the Department of Building Technology, recommended that one direction of approaching the problem is to look at the membrane structures, especially the temporary constructions built for the Hannover Expo 2000. Japanese architect, Shigeru Ban, among others, utilized innovative methods for constructing tensile structures. Clues can then be drawn from some of these details involving fabric connections.

[7.2] Shigeru Ban's famous paper tube structure at the Hannover Expo 2000.



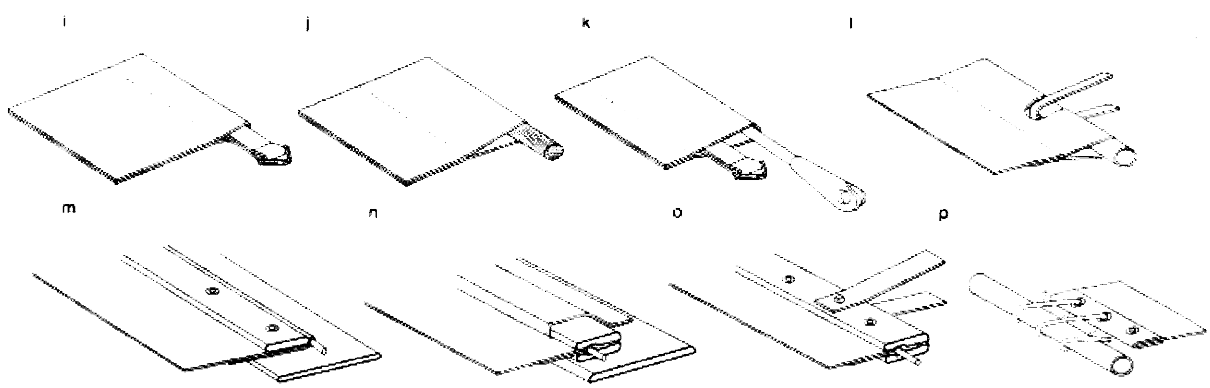
[7.3]

Seams within area of membrane:

a. high-frequency welded seam in PVC-polyester fabric
b. high-frequency welded seam in PTFE-glass-fiber fabric with PTFE intermediate membrane strip
c. sewn seam with PVC-polyester sealing strip
d. clamping strips

Membrane reinforcement:

e. doubling layers; low loading
f. doubling layers; heavy loading
g. cable in sheath
h. strap in sheath



[7.4] Examples of possible connection techniques of tensile structures featured in Detail Magazine, June 2000

Edge fixings:

i. peripheral strap sewn in
j. cable in sheath
k. edge cable and strap
l. tube in sheath
m. edge clamping plate with perforation of membrane; tensioning not possible
n. edge clamping pates without perforation of membrane; tensioning possible
o. edge clamping plates with fixing straps
p. tied edge

2. enclosure

   The material for the enclosure of the building is meant to be ultra-lightweight as well. Transparent polymer could be used for an exposure of the structural mesh, while solid polymer panels with carefully cut-out slits could be an interesting way to bring out the curves of the tower. Because of the woven property of the structural mesh, one could also be weaving colorful fiber optics through the building to give it a more playful tone during special occasions or festivals.

[7.5] fiber-optics could be woven within the structure mesh skin to give it a more playful tone.

3. optimization

   Since the form of the tower is generated by forces from the site and program, it is, by all means, not optimized for structure. It is possible that a structurally-optimized form could end up with some kind of symmetry. The form demonstrated in the design is therefore an attempt to push the limitation of the form while retaining the same building system. It would be an interesting investigation of the system if one were to generate tower forms that optimize structural performance. In that case, specific loading forces, placement and sizes of the cores, as well as the mesh pattern density and structure, will be several of the key issues involved.

The process of investigating composites as building materials during this thesis project has led to a new way of design thinking in architecture. From the examination and exploration of these materials and their applications, one realizes that other design industries, such as product, automotive, aerospace, engineering, fashion and graphics design, are merging into one big realm of creativity. Utilizing the advances in computing technologies as common platform, these various design fields are beginning to share techniques, whether it involves design, fabrication, visualization or manufacturing. This situation could have tremendous benefits to the design industry in general and result in an environment where also the sharing of research and development in materials and technology can take place. For us architects, this integration of design fields may also symbolize a possible change in our future roles. We will definitely be looking forward to that.

"Obstacles to expanding architectural services are dissolving. Architects can now think beyond the creation of static spaces,simple structures, and limited obligations. Architect as behavioral scientist, manufacturer, and technical coordinator may very well describe the specialties of the next century."

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[2.18] *http://www.mbusa.com*

[2.19] *http://www.imagebank.com*

[3.1] Hong Kong – City of Vision

[3.2] *http://www.hkta.org*

[3.3] *http://www.hkta.org*

[3.4] Hong Kong – City of Vision

[3.5] Hong Kong – City of Vision

[3.6] Hong Kong – City of Vision

[3.7] Building materials and technology in Hong Kong

[3.8] *http://www.imagebank.com*

[3.9] Building materials and technology in Hong Kong

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[3.13] Hong Kong Survey and Mapping Office

[3.14] Architectural Service Department, Hong Kong

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[3.16] *http://www.hkta.org*

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[4.4] *http://www.imagebank.com*

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[4.6] Gehry Talks

[4.7] Polymer Composites for Civil and Structural Engineering

[4.8] *http://web.mit.edu/arch/edg*

[4.9] Richard Deacon

[4.10] Richard Deacon

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[4.12] The Genius of Charles James

[4.13] The Genius of Charles James

[4.14] Your Private Sky, R. Buckminster Fuller

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[4.18] *http://www.hkta.org*

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[4.20] *http://www.xvbeacon.com*

[4.21] *http://www.xvbeacon.com*

[4.22] *http://www.xvbeacon.com*

[6.1] photo taken by Devyn Weiser

[6.2] photo taken by Devyn Weiser

[6.3] photo taken by Devyn Weiser

[7.4] Detail Magazine

[7.5] Detail Magazine

resources

hardware:

Dell Precision Workstation 420
Dual 1-Ghz Pentium III processors
512 mb of RDRAM
36 gig Hard drive

Fujifilm Finepix 4700 Digital Camera
With 32mb smart media card

software:

Autodesk AutoCAD 2000
Autodesk Mechanical Desktop 5
Kinetix 3D Studio Max Release 3.0
Adobe Photoshop 5.5
Adobe Pagemaker 6.5
Rhinoeros 1.0
Quickslice 6
Macromedia Dreamweaver 3