A temporary ferry terminal with green consciousness:
A sustainable design

by

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has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

Dedication

To my father:

your courage in fighting against disease inspires me

to achieve this point in my life. I am one of your

steadfast allies. We will win the battle.

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Introduction

Background

"Two centuries after the dawn of the industrial age, the world on Wednesday took its first concerted step to roll back the emission of "greenhouse gases" believed linked to climate change with the enactment of the Kyoto global warming pact."

The Associate Press 2.16.2005

Although several of the wildest horses in the world are still running out of the barn and for all the Kyoto Protocol's imperfections, it is the best movement so far to reduce human beings' negative impact on the natural environment. It wasn't until hundreds of years after the Industrial Revolution that the whole world realized that the environment is not an endless supply of natural "capital." [1] One statistic makes clear the demand placed on the earth by our economic system: every day the worldwide economy burns an amount of

Year	Event
1972	'The Limits to Growth' Report
1972	Stockholm Conference on the Human Environment (UN)
1979	Berne Convention on Habitat Protection (Council of Europe)
1979	Geneva Convention on Air Pollution (UN)
1980	World Conservation Strategy (IUCN)
1980	Global 2000 Report (USA)
1983	Helsinki Protocol on Air Quality (UN)
1983	World Commission on Environment and Development (UN)
1987	Montreal Protocol on Substances that deplete the Ozone Layer (UN)
1987	Our Common Future (Brundtland Commission on behalf of the UN)
1990	Green Paper on the Urban Environment (EC)
1992	Rio Summit Agreements (UN)
1992	Our Common Inheritance (UK)
1994	European Environment Agency established (EU)
1997	Kyoto Conference on Global Warming

Table 1, International milestones of environmental agreement or awareness (Source: Edwards, Brain. *Sustainable Architecture, European Directives And Building Design,[Architectual Press, 1999], xiii.)*

1. McDonough, William, and Braungart, Michael, *Cradle to Cradle*, (New York: North Point Press, 2002), 24

energy the planet required 10,000 days to create. Or, put another way, 27 years worth of stored solar energy is burned and released by utilities, cars, houses, factories, and farms every 24 hours.[2]

Among all human behaviors, the building sector plays a significant role in environmental impacts, as it is one of the major sources of energy consumption.[3] Various building related activities, such as material production, construction, operation, maintenance, refurbishment, and demolition, contribute directly or indirectly to many environment problems. In the United States buildings use over 36% of the primary energy use, 65% of the electricity consumption, and 30% of the greenhouse gases emissions. [4] Emissions from the use of energy in the building sector are among these impacts on the earth, which lead to acid rain, ground-level ozone, smog, and global climate change. Taking these issues into account, architects are expected to take on a greater responsibility for the world's energy consumption and greenhouse gases emissions. Meanwhile, buildings fundamentally influence people's health and lives. The obligation of the architect lies in building sustainable architectures that add something to people's lives and make them easier. [5]

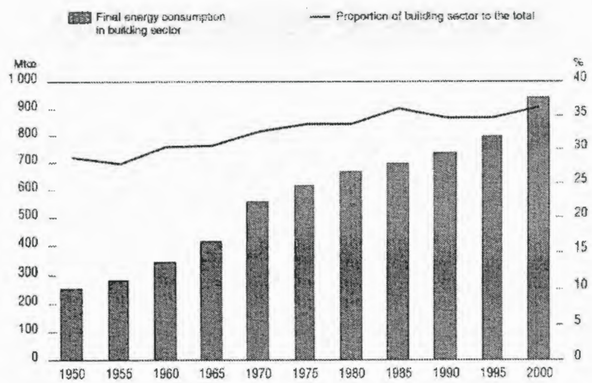

Figure 1, Proportion of building sector to the total energy consumption of the U.S.(Source: US Department of Energy, 2001)

2. Hawken, Paul, *The Ecology of Commerce*, (New York: HarperCollins Publishers, 1993), 21-22
3. OECD, *Environmentally Sustainable Buildings- Challenges and Policies*, (OECD, 2003), 6
4.USGBC, *Why Build Green*, USGBC, http://www.usgbc.org/DisplayPage.aspx?CMSPageID=38, (accessed February 8th, 2005)
5. Piano, Renzo. *Sustainable Architectures = Arquitecturas Sostenibles.* (Gingko Press, 1998), 56

Introduction

In the very beginning of human history, we respected nature and admired its great power. Original nature is so powerful that only by interpreting it, only by using its own norms, can another feature be created. [6] In traditional Chinese philosophy, a harmonious balance between man and nature is an ideal status, which would give birth to health, fortune, and prosperity. Feng Shui—literally "wind" and "water," is a concept used to interpret the mysterious forces of nature. [7] An typical ideal house would be located halfway up a hill on the north side of the river facing south. Such surroundings would allow the house to receive plenty sunlight, be prevented from harsh winds, and have good accessibility to water for crops. The proper harnessing of "wind" and "water", the force of nature that ripples water, creates different landscape, embraces various lives, which is crucial to create a harmonious balance between man and nature. [8]

Not until the Industrial Revolution did people begin to abandon their respect toward nature. People thought natural resources will never be exhausted. Industry and construction activities drew unrestrainedly on the earth's resources. Building was seldom treated by designers as a part setting within a

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6.Piano, Renzo. *Sustainable Architectures = Arquitecturas Sostenibles.* (Gingko Press, 1998), 58.
7.Zeiher, Laura C, *The Ecology of Architecture*, (New York: Whitney Library of Design, 1996), 10.
8. Ibid

bigger nature system. Instead, the design criteria were usually limited to the issues about aesthetic delight, practicality, and spatial efficiency. Environmental consciousness did not become a vibrant force in design and construction until we started to see a series of environmental damages and climate changes. Even then it took a long time before sustainable design has aroused widespread awareness all around the world. The issue of how a building interacts with other sectors in the nature system during its life-cycle time usually was not the consideration of the architects who had no environmental consciousness. In fact, when a building finishes its journey on the earth, the destination of almost all embodied valuable resources and materials is unconsciously predefined to be buried into landfill. McDonough described the linear path as "from cradle to grave," [9] because those energy and materials will never get chance to be revitalized in this planet.

Imagine a designer has been given a job of designing a roughly 70,000 square feet complex building. Without environmental consciousness at the beginning of the design, the negative consequence of the building would likely be as follows:

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9. McDonough, William, and Braungart, Michael, *Cradle to Cradle*, (New York: North Point Press, 2002), 27

- Thousands of tons carbon dioxide will be poured into the air.
- Thousands of tons of water will be used during the stages of building materials acquisition, transportation, and construction.
- Huge amounts of waste materials will be produced.
- Thousands of dollars a day will be spent to control the indoor environment by using a mechanical HVAC system.
- People are isolated from natural sunlight, air and views.
- Diversity is diminished by standard units.
- Most materials finally can only be buried to landfill.

Such negative consequences are not intended. Actually, the designer was working hard to design the project to make the building more attractive. But the true outcome of the building's life cycle is a lack of environmental design. As the result, the overall environmental quality is in decline. A healthy, built-up environment can not be a result of a design without the designer adhering to an environmentally responsible attitude from the beginning.

Nature does a perfect job in renewing its resources and energy flow, until the cyclical system was interrupted and overused by man with a linear, one-way attitude of resources. As limited natural resources and the quality of the built-up environment have aroused widespread concerns since the last decade, it is time to reevaluate our conventional linear attitude. Nature always indicates a solution: to mimic its highly effective cyclical system of nutrient flow and metabolism. Thus, we should renew the resources and energy flow embodied in buildings. What we get from nature should at least equal to what we can give back to the nature. In McDonough words, we should design buildings "from cradle to cradle." [10]

So, in terms of the life cycle of buildings, a design without long-term consideration about the environment, buildings, and embodied energy, and without consideration within the larger natural system, is to keep putting buildings on a liner journey "from cradle to grave." The earth can not sustain such a system if we keep sending natural resources and materials into landfills, which ends up rendering the materials nearly useless. If we truly want our built-up environment to be healthy and provide us with high quality life in the long term, we need to adopt this cradle-to-cradle system in our building sector, in other words, a "cyclical, closed-loop system." [11]

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10. McDonough, William, and Braungart, Michael, *Cradle to Cradle*, (New York: North Point Press, 2002), 104
11.Mendler, S. Odell, W. *The HOK Guidebook to Sustainable Design*, (John Wiley & Sons, INC. 2000), 7

Definitions

Although there are many definitions of sustainability in terms of the different perspectives of research areas, they share some understandings in common. Some focus on socio-economic issues, others focus on the inter-relationship between humans and natural systems. Among them, the concept of sustainable development, from the World Commission on Environment and Development in 1987, gained wide acceptance. It defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [12]

From the perspective of an architect, sustainable design emphasizes the full understanding of the interdependence of the built-up and natural environments. It seeks to obey the laws of nature, harness natural energy flows and biological processes, eliminate reliance on irreplaceable fossil fuels and toxic materials, and improve resource efficiency. [13] It enjoys the diversity of nature and culture, and gathers inspiration from the diversity. In stead of a new building "style". [14] Sustainable design is a manner of how we think about design, construction, and operation of buildings. Based on the attitude of environmen-

12. UNECSO United Nations Educational, Scientific and Cultural Organization,http://portal.unesco.org/education/en/ev.php-URL_ID=23279&URL_DO=DO_TOPIC&URL_SECTION=201.html, (accessed January 3rd, 2005).
13. Mendler, S. and Odell, W. *The HOK Guidebook to Sustainable Design*, (John Wiley & Sons, INC. 2000), 6.
14. Rocky Mountain Institute, *A Primer On Sustainable Building*, (Rocky Mountain Institute ,1995), 2

tal consciousness, an architect's job is to create a healthy and pleasant build-up environment.

The Rocky Mountain Institute, a pioneer in the United States in sustainable design, offers several criteria that an ideally sustainable building should meet. A sustainable building should

1. make appropriate use of land

2. use water, energy, lumber, and other resources efficiently

3. enhance human health

4. strengthen local economies and communities

5. conserve plants, animals, endangered species, and natural habitats.

6. protect agricultural, cultural, and archaeological resources

7. be nice to live in

8. be economical to build and operate [15]

Similarly, The United State Green Building Council's definition stresses the environmental consciousness in different design areas:

Design and construction practices that significantly reduce or eliminate the negative impact of buildings on the environment and occupants in five

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15. Rocky Mountain Institute, *A Primer On Sustainable Building*, (Rocky Mountain Institute ,1995), 7

broad areas:

- *Sustainable site planning*
- *Safeguarding water and water efficiency*
- *Energy efficiency and renewable energy*
- *Conservation of materials and resources*
- *Indoor environmental quality* [16]

Although different in verbal expression, many leading green practicers share something in common as summarized as follows:

1. Emphasis on site planning for sustainable development
2. Conversation of valuable natural resources and materials.
3. Minimization of construction and demolition waste (C&DW) [17]
4. Focus on energy efficiency and taking advantage of the renewable natural resources
5. Prevention of pollution, and the improvement of indoor environment

These accompany with the later discussed LEED checklist will serve as guidelines to judge the achievement of the design in this thesis.

16. USGBC, *An Introduction to the U.S. Green Building Council and the LEED Green Building Rating System®*, 2004, https://www.usgbc.org/Docs/Resources/usgbc_intro.ppt, accessed Jan 10th, 2005
17.OECD, *Environmentally Sustainable Buildings- Challenges and Policies*, (OECD, 2003), 7

Problem

This thesis rests on my interest of taking environmental responsibility to initiate design ideas for a temporary ferry terminal. Each building in my design is regarded as an organic component in the larger natural system. When a sustainable building begins its journey, it will not compromise nature's capacity to render its system still valuable for the future generations. I am interested in developing a sustainable design following a "cyclical, closed-loop" track,[18] as the design solution. Natural elements like sunlight, air, water, wind, and landscape features should have their value and existence reflected in the design process. Although these features are so common that we often unintentionally neglect them, whether or not we let nature's voice heard in a design process makes a significant difference in the success of a sustainable building design.

The ferry terminal discussed in this thesis is one of the ground transportation hubs of Shenzhen International Airport, the fourth busiest airport in mainland China. It serves passengers taking Hong Kong-Shenzhen-Macao turbojet seaway shuttles. According to the comprehensive plan of the airport, the current site is supposed to be converted to be part of the roadbed for the air-

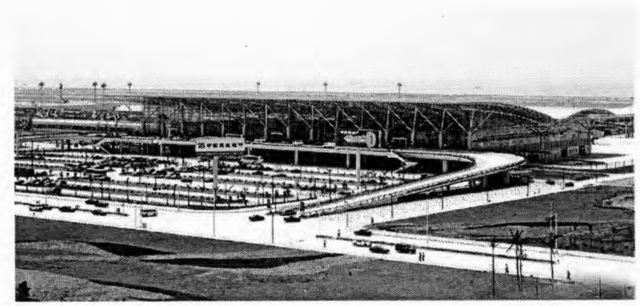

Figure 2, Aerial view of Shenzhen International Airport

Figure 3, Terminal of Shenzhen International Airport

18. Mendler, S. Odell, W. *The HOK Guidebook to Sustainable Design*, (John Wiley & Sons, INC. 2000), 7

port's second runway expansion 15 years later. So the building will only have about 15 years life span, either to be demolished or moved to a new site.

Sustainability consists in building while thinking of the nature. [19] If we regard the existence of a building as a journey, how can we relieve the environmental burden of this journey? How can we achieve a balance between nature law and functional needs without compromising the future development? If it's a journey, how to make sure that it is right on the track of "from cradle to cradle"?

To better understand the design of the temporary ferry terminal, I need to look closely to several challenges inherent in the project. One challenge is the life span of the building. Benefits of a sustainable building usually take a long time to manifest themselves. For instance higher energy efficiency, lower maintenance costs, and healthy socio-ecosystem requires time for sustainable design efforts to prove their success. However, for a short term building used for only 15 years, like in this case, will sustainable practice still be able to achieve long term significant benefits?

Second, construction and demolition waste (C&DW) issue. Potential

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19. Piano, Renzo. *Sustainable Architectures = Arquitecturas Sostenibles.* (Gingko Press, 1998), 56

C&DW for such a 70,000 square feet area will cause a series problems in this rainy waterfront site. The conventional process of construction and demolition usually takes a long time to build and demolish, causes a large amount of waste, including materials, energy, solid waste, green gases emission, and waster water, which are hard to recycle and process. Moreover, storm water runoff will carry C&DW pollutants from the site directly flows into seawater, which may undermine the water quality. Are those wastes produced during the process of construction and demolition avoidable? If not, how do we minimize the C&DW of this temporary building?

Third, the process of construction and demolition and the structure type, both make a difference for a temporary building. The activities of construction and demolition usually impact on the environment through site disturbance, air pollutants, storm water runoff, materials and solid hazardous wastes. All these have the potential to alter the natural ecosystem. One tentative way to address this challenge is to use local prefabricated materials to both speed the construction and demolition process and reduce the impact on the surrounding environment. Usually it also reduces the cost in building. Meanwhile, different structures require different time and labor consumption. Each construction or structure type causes different a different impact on environment. So, it there a way we can build such a temporary building quickly and efficiently? As for building material conservation, an optimized structure type can preserve more precious materials and embodied energy than a conventional type.

The fourth challenge is indoor environment quality. In terms of a terminal building, most current terminals are predefined as a huge, long-spanning structure, where people are fully enclosed by glass, metal, or concrete envelop. The direct contact with sunlight, wind, fresh air, and even views is obstructed by the building envelop. Enormous energy is consumed by heating, ventilating, and air conditioning (HVAC) system. The indoor climate is totally controlled by expensive and energy-greedy mechanical system. People are isolated from the natural environment by artificial equipment. As for this ferry terminal, large amounts pf passengers gather in the building everyday. Inefficient HVAC system will cause "sick building" syndrome. [20] The air quality in a build-up environment should get more consideration. Meanwhile, natural sunlight is a renewable and powerful energy resource. However, artificial lighting fixtures,

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20. Rocky Mountain Institute, *A Primer On Sustainable Building*, (Rocky Mountain Institute ,1995), 83

which consume enormous electric power annually, are often abused in the building sector even when natural light is more efficient and free. So, my forth challenge is, how can we provide end-users with healthy indoor air quality and physical spatial delight in this public facility?

Taking all these into account, I will focus the design resolution on **site development, material conservation, water, energy efficiency, and indoor environmental quality**. The design will also reflect how the environment consciousness drives the design process. By doing so, the design with environmental responsibility will result in:

- **uses resources efficiently, including energy, water, land, and materials**
- **moves toward eliminating environmental impacts, CD&W, and pollution**

  In the production of the materials used in the building
  In the construction of the project
  In the operation of the building
  In the ultimate disposal of the building and its components

- **Creates healthy indoor environment**

Site

The site of the temporary ferry terminal is located in the fringe of Shenzhen, China, a booming city experiencing rapid growth that transformed it from several remote fishing villages to a giant urban place with 7 million inhabitants during the last two decades. Shenzhen has a subtropical maritime climate with plenty of rain and sunshine. It is never blazingly hot in the summer and the season can last for as long as six months. It is mild in spring, autumn and not very cold in winter. The rainy season lasts from May to September. Typhoons usually occur in summer and autumn, while most typhoons are obstructed by mountains. The annual average temperature is 22.4°C (72 °F), with the highest temperature being 36.6 °C (98 °F) and the lowest 1.4 °C (35 °F). The year's frost-free period can be as long as 355 days. [21]

The City of Shenzhen, China's representative economic prototype, is developing into a leading high technology center of the country: about 46% of production comes from high-tech companies replacing the older branches of textiles and machine construction. [22] 50% of Chinese information technology products are already manufactured in Shenzhen. The GDP per capita has

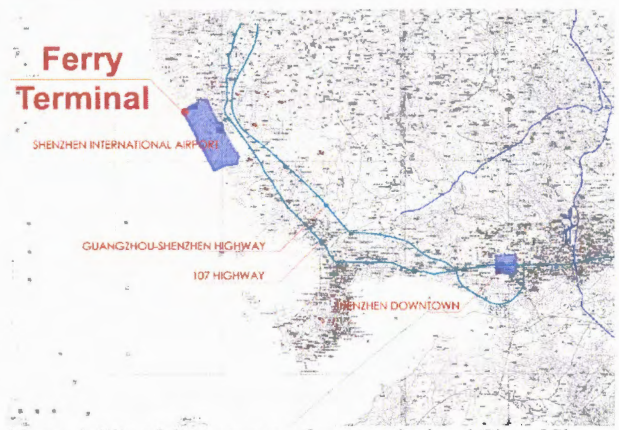

Figure 4, Site of the temporary ferry terminal and City of Shenzhen

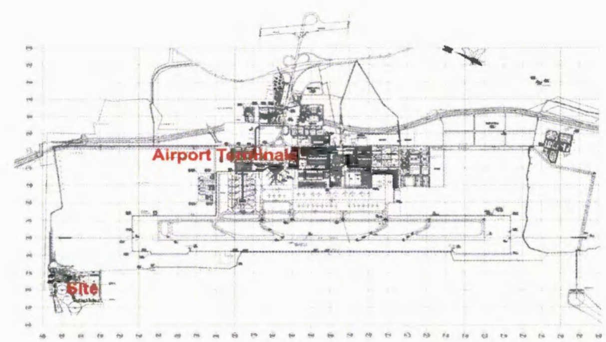

Figure 5, Site of the temporary ferry terminal and Shenzhen Airport

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21. China Highlights, *Shenzhen Brief Information*, http://www.chinahighlights.com/shenzhen/briefinfo.htm (accessed January 6, 2005,)
22. City of Shenzhen, http://www.sz.gov.cn/english/gs/gi.htm (accessed December 22, 2004).

become the highest in mainland China since last decade. Meanwhile, logistics, finance, and information services are leading sectors in the country. The culture in Shenzhen is quite different with others cities in China. The city is a made up of immigration from all over the country, and most of the residents are young. After growing from several fishing villages to a metropolis, few traditional relics can be found in young Shenzhen. The fast growing metropolis is also visibly expressing itself by skylines with thousands of high-rise buildings, two of which are among the highest in the world. [23]

The current site for the ferry terminal is a mixed-use port facing the South China Sea. It includes a ferry terminal, offices, warehouses, a police station, open-air bulk yards, tons of containers, parking lots, and facilities for the harbor. The site is remote from any neighborhoods, three miles away from airport terminal, and 28 miles from downtown Shenzhen. The ferry is able to accommodate several thousand-ton cargo berths and two passenger berths.


Figure 6, City of Shenzhen, China


Figure 7, View of site and mixed-use port

23. Wikipedia, http://en.wikipedia.org/wiki/Skyscraper, (accessed January 2, 2005)

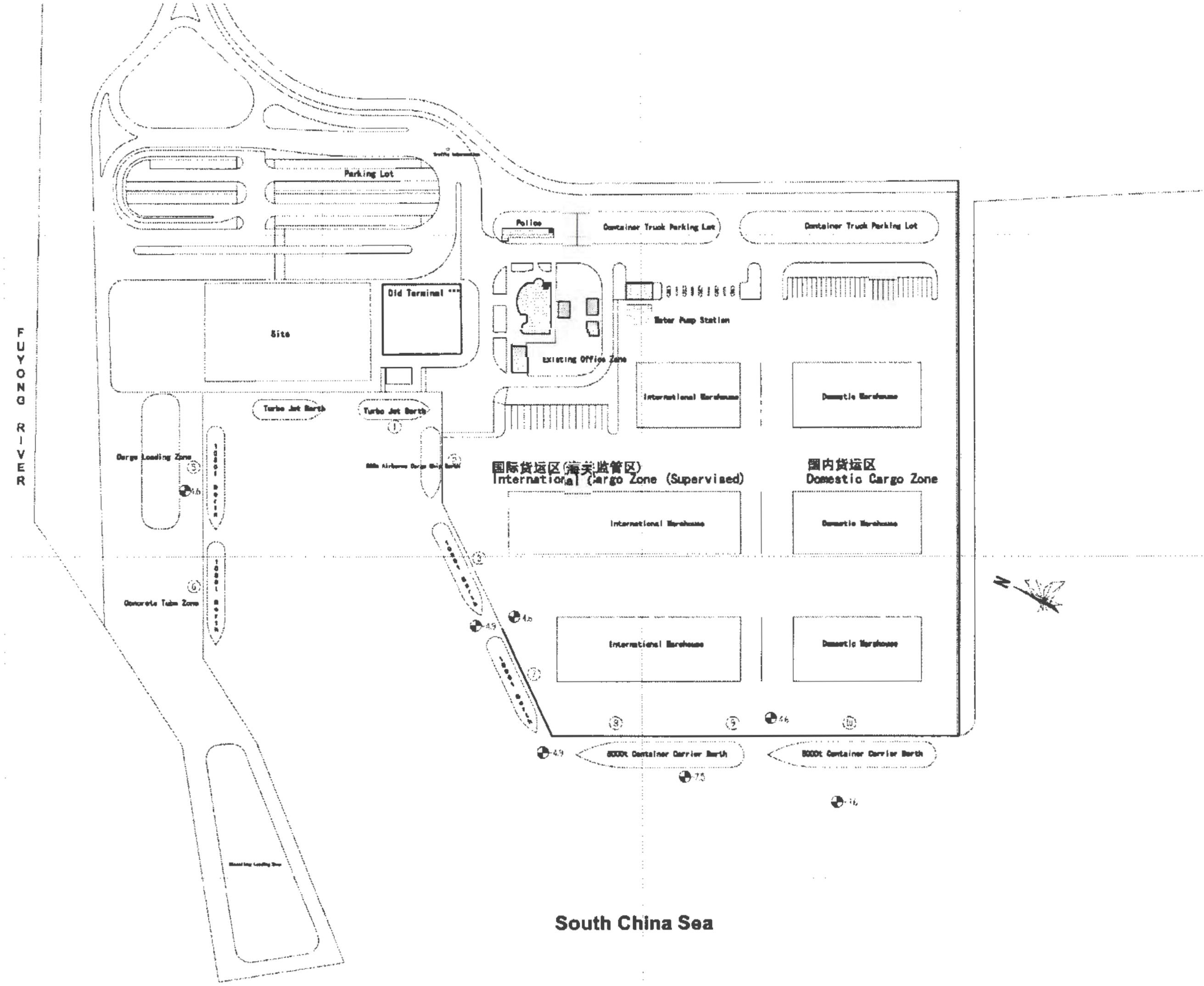

Figure 8, Site plan

Program

The ferry terminal will serve passengers traveling between Shenzhen, Hong Kong, and Macao. The amount of passenger will grow rapidly to 930,000 per year. [24] Terminal shuttle buses, taxi, and private cars carry passengers either from airport terminals or from the city of Shenzhen. The rush hours of the ferry terminal will be at 8:30-10:00am, 1:15-2:00pm, and 4:30-5:30pm. [25]

After arriving at the ferry terminal, passengers, whose destination is Hong Kong or Macao, need to go through the checkpoints including Quarantine – the Customs - Immigration - Security Check, and go to the boarding hall. For arrival, passengers go through the border procedure including Quarantine - Immigration – the Customs. The passenger amounts of arrival and departure are expected to be similar in the foreseeable future. Each area will need 6 gates for inspection. So the arrival section and departure section have the similar area demands. In addition, there are some waiting space, duty free shops, offices, and mechanical rooms required to operate the ferry terminal.

24.Shenzhen Airport, http://share.jrj.com.cn/cominfo/ReadDetail.asp?Folder=2004-08-10&StockCode=000089&ID=191085 (accessed December 22, 2004).
25. Ibid

Literature Review

Build more with less

"Less is more", a phase by Mies van der Rohe, is best known as an explanation of elegant steel and glass architecture since the mid 20th century. However, for a sustainable design, "Less is more" might have a different meaning. Various building materials consume enormous amounts of energy throughout the process of raw material hauling and mining, manufacturing and fabrication, construction and demolition.

Take concrete for instance. Concrete is the most common construction material used in China. Producing concrete is a highly energy-intensive process. Cement, the major component of concrete, is responsible for a series of environmental impacts, including greenhouse gases emission, dust, soil erosion, habitant alteration, and wastewater. Currently, there are many economical and technical barriers prevent materials being fully recycled. If we regard the life-cycle existence of various materials in building as a journey, most embodied valuable natural resources and energy under current circumstance, will travel from "cradle to grave". Therefore minimizing the usage of building material, especially those energy greedy materials, is crucial to preserving precious natural resources.

Buckminster Fuller, one of the key innovators of the last century, also the inventor of the Geodesic Dome, attempted to anticipate and solve humanity's major problems by providing "more and more life support for everybody, with less and less resources." [26] In 1960, Buckminster Fuller experimented with the newest technology to make efficient buildings for everyone. The geodesic dome encompasses a great amount of space with minimum materials and expense. By using this innovative structure, Fuller significantly reduced the demand of materials. Structure system preliminarily defines the demand for building materials. So, to conserve building materials and nature resources, it is crucial to deciding on the structure system for the ferry terminal.

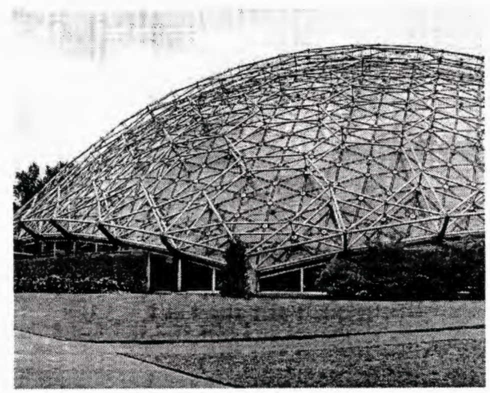

Figure 9, Cyclatron Geodesic Dome, St.Louis, MO, Buckminster Fuller, 1960. He set out to build more with less. The geodesic dome encompasses great amount of space with a minimum of materials and expense. (Source: Zeiher, Laura C, *The Ecology of Architecture*, [New York: Whitney Library of Design, 1996], 10)

26. The Buckminster Fuller Institute http://www.bfi.org/introduction_to_bmf.htm (accessed January 2, 2005)

Tensile Structure

Instead of doing justice to today's needs, in colossal arrogance our buildings claim fixed values for an indefinite time. We need buildings fulfill their task today and will do so tomorrow, which, in other words, do not age in adhering to forms and thus become a drag. But in order to build adaptability, we must try to build as lightly, as movably, as possible.

Frei Otto, 1960

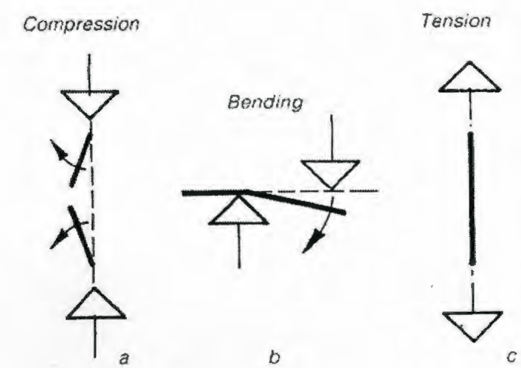

Figure 10, Structure components are most efficient in thension. (Source: Vandenberg, Maritz, *Soft Canopies*, [London, UK: Academy Editions, 1996], 6)

To build more with less, tensile structure has proved its excellent capability to cover a large space,and make a space more flexible for multiple purposes, while using a minimal amount of material. Pure tension is by far the most efficient way of using a slender structure member. [27] Tension roofs are those in which every part of the structure is loaded only in tension, with no requirement to resist compression or bending forces. [28]

When we talk about reducing waste, unnecessary parts in the building structure also physically waste valuable natural resource. Conventional

27. Vandenberg, Maritz, *Soft Canopies*, (London, UK: Academy Editions, 1996), 6
28. Ibid

structures like steel trusses or concrete beams have to spend enough materials to deal with compression or bending forces; however, these materials are avoidable by using tensile structure. The perfect candidate is a structure in which every part is working to maximum efficiency. Tensile system is such a high-performance structure. Actually the tensile structure is not as high-tech as one might imagine. The nomad tent was the prototype of modern tensile architecture. As early as the 1st century, the Chinese began to use intertwined outer layers of bamboo as cable for long span suspension bridges. [29] The use of sophisticated tensile structure in sailing ships, such as the rigging of the Chinese junk in Victoria Bay, Hong Kong, where is one of the major destinations for the passengers in the ferry terminal, has been used for millennia. [30] Modern membrane structures have been advanced tremendously by Frei Otto, whose Olympic roof with cable net structures and other wide-span roofs made from coated fabrics in Munich is widely regarded as a milestone. [31] Since then, roofs made of coated fabrics became an established type of construction.

There are two types of fabrics most commonly used for fabric tensile structure, PVC (Polyvinyl Chloride)-coated polyester and PTFE (Polytetraflu-

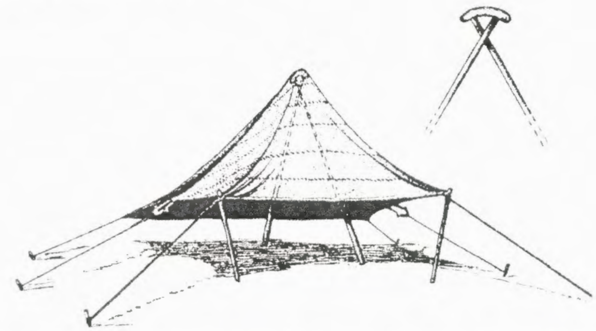

Figure 10, A nomad tent from Moroccan. (Source: Berger, Horst, *Light Structures, Structures of Light*, [Basel, Berlin, Boston: Birkhäuser, 1996], 22)

Figure 11, A traditional Chinese junk with tensile technology in in Victoria Bay, Hong Kong

29 Drew, Philip, *Tensile Architecture*, London, Toronto, Sydney, (New York: Granada Publishing, 1979), 124

30. Berger, Horst, *Light Structures, Structures of Light*, (Basel, Berlin, Boston: Birkhäuser, 1996), 23

31. Schock, Hans-Joachim, *Soft Shells-Design and Technology of Tensile Architecture*, (Basel, Berlin, Boston: Birkhäuser, 1997),7

Figure 12, Interior of the swimming pool, Munich, by Frei Otto. (Source: Drew, Philip, *Frei Otto: Form and Structure*, [Westview Press, 1976], 106)

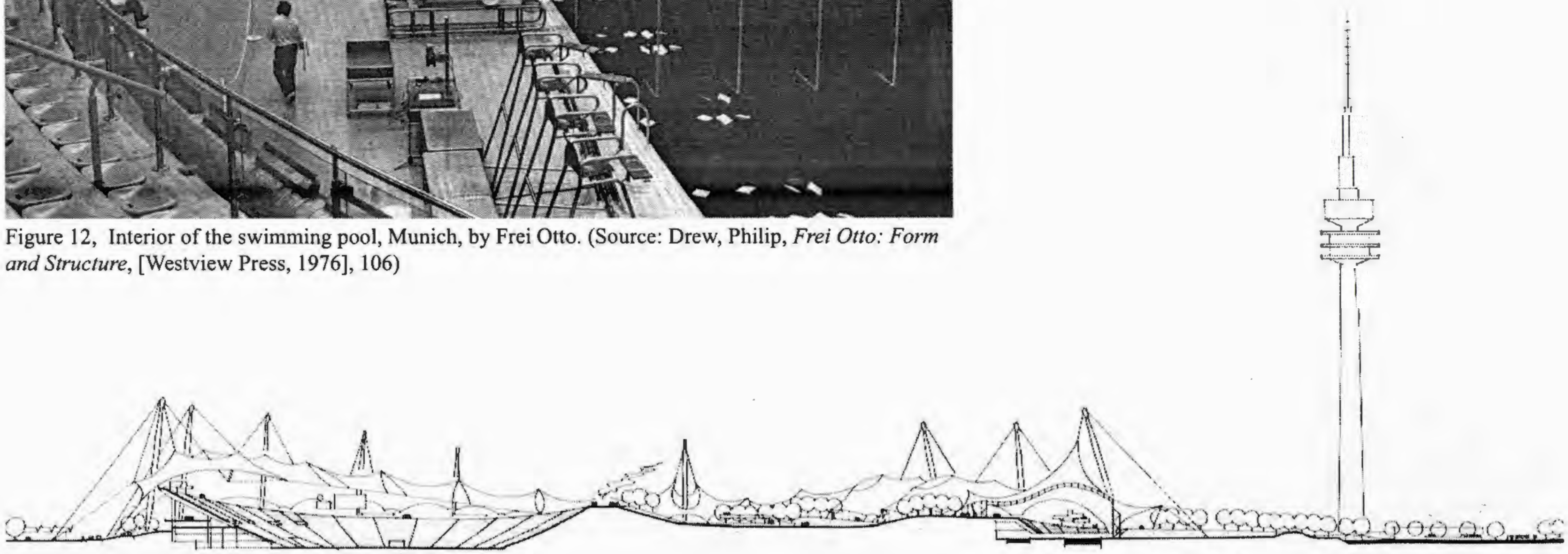

Figure 13, Section through the overall tensile structure complex, main sports area, Munich, by Frei Otto. (Source: Drew, Philip, *Frei Otto: Form and Structure*, [Westview Press, 1976], 99)

Table 1 Properties of the two fabrics most commonly used for soft canopies

Property	Fabric PVC-coated polyester	PTFE-coated glass
1. Short-term structural properties:		
Tensile strength	Medium	High
Tensile modulus	Medium	High
Tear strength	Medium	High
Directionality	Normally stiffer in the warp direction than the weft but there are fabrics available with virtually identical properties in both directions	As for PVC-coated polyester
2. Long-term structural properties:		
Construction stretch	Medium	Low
Dimensional stability	Medium	High
3. Non-structural properties:		
Durability	Lifetime normally 10 to 12 years depending on (a) exposure and (b) opacity of coating. Design life could be only 3 to 5 years with highly translucent coatings and up to to 15 years with opaque coatings. A white finish will reduce surface temperature and enhance durability	25 years or more
Translucency	8% to 30%	5% to 15%
Appearance	All colours available. Can be opaque or translucent. Suffers from dirt retention so that visual rather than physical deterioration is likely to determine working life	White and a few other colours are available. Dirt is not retained and surface remains clean. No discoloration
4. Ease of installation:		
Flexibility	High, making for easy fabrication, transportation and installation	Low, creating a risk of damage during fabrication, transportation and installation. Accurate cutting and installation vital.
Jointing	Easily done	Specialist techniques needed
5. Summary comments:		
	Overall the most popular coated fabric, and there are many experienced installers. Cheap enough to be replaced every 10 years to maintain pristine appearance	Used for canopies where long life and/or low maintenance are more important than low cost or ease of installation

Table 2, Properties of the two fabrics. (Source: Vandenberg, Maritz, *Soft Canopies*, [London, UK: Academy Editions, 1996], 29) orethylene or Teflon)-coated glass fiber. PVC-coated polyester is easier to work and is cheaper in first cost than PTFE-coated glass fiber. But PVC is less durable, requires more cleaning, and stretches more under load. PTFE-coated fabric will last more than 25 years. [32]

Fabric tensile structure is defined as the fabric roofs, which are thin, flexible membranes held in shape by the application of tension,that act simultaneously as structure and as a weather shield. [33] Fabric tensile architecture, constructed by masts, cables, and membranes, features some significant properties: it is lightweight, flexible, thin material, covering large spans without intermediate supports; it has an almost endless diversity of curved surface shapes; it is visually light with thin edges, if desired transparent or translucent; and it is also physically light for transportation, quick and easy to erect. [34]

Haj Terminal 1978, Jeddah Airport, by SOM features fabric tensile structure as an exploration of the phrase "build more with less." It also offers protection against the heat of the desert sun. The terminal is located in Saudi Arabia. On a typical Jeddah day, with an ambient air temperature of 35°C (95 °F), a conventional enclosed concrete or metal roof exposed to the desert sun

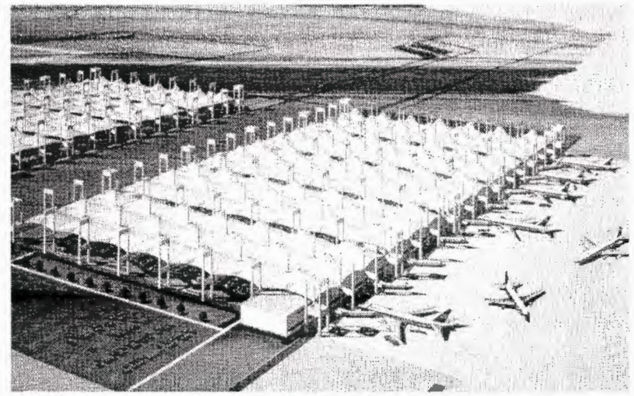

Figure 14, Jeddah Haj Terminal. The 105-arce roof consists of 10 modules, each of 21 tent units. (Source: Berger, Horst, *Light Structures, Structures of Light*, [Basel, Berlin, Boston: Birkhäuser, 1996], 78)

32. Vandenberg, Maritz, *Soft Canopies*, (London, UK: Academy Editions, 1996), 26-29.
33. Vandenberg, Maritz, *Soft Canopies*, (London, UK: Academy Editions, 1996), 6
34. Schock, Hans-Joachim, *Soft Shells-Design and Technology of Tensile Architecture*, (Basel, Berlin, Boston: Birkhäuser, 1997), 7

would reach temperatures in the order of 65 °C (150 °F). Because of its mass, such a roof would collect and radiate a considerable amount of heat into the building. Electric lighting--necessary under an opaque roof-- would also add to the heat load. [35]

By reflecting most of the sun's heat, a fabric tensile structure using Teflon-coated glass fiber would maintain its surface temperature within a few degrees of the ambient air. As a result, the fabric's temperature would not rise much above 40 °C (104 °F), while its translucency would make artificial light unnecessary during the daytime. Most of the impact of the desert sun is eliminated, reducing the heat to the level encountered in the shade of trees. At the same time, mechanical energy is also drastically reduced. [36] Because no artificial lighting is needed during the daytime, no electric energy from lighting needs to be absorbed and carried away by cooling system. Air conditioning is not imperative even in hot climates, since ventilation openings can be installed easily, and a large portion of the thermal radiation is reflected by Teflon-coated roof. As an additional benefit, fabric tensile structure had a short construction period and quick erection, for such a project with large space. [37]

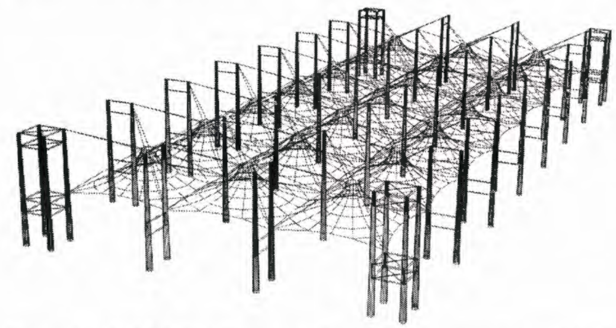

Figure 15, Jeddah Haj Terminal. Structural system in simplified form. (Source: Berger, Horst, *Light Structures, Structures of Light*, [Basel, Berlin, Boston: Birkhäuser, 1996], 80)

35. Berger, Horst. *Light Structures, Structures of Light*, (Basel, Berlin, Boston: Birkhäuser, 1996), 77
36. Ibid
37. Ibid

LEED

Leadership in Energy and Environmental Design (LEED), which is developed by the United States Green Building Council, is a popular tool for green building evaluation. It provides a complete framework for assessing building performance and meeting sustainability goals. [38] The current LEED V2.1 system for new commercial construction summarizes sustainable design into six categories:

1. sustainable sites
2. water efficiency
3. energy & atmosphere
4. materials and resources
5. indoor environmental quality
6. innovation and design process

Although far from perfect, LEED V2.1 is one of the best green rating systems so far. The LEED system will be used as a measurement for my thesis project. A detailed LEED V2.1 checklist for such a new commercial building is attached in appendix.

38. USGBC http://www.usgbc.org/DisplayPage.aspx?CategoryID=19 (accessed November, 2004)

Water

There are more and more low-temperature seawater cooling systems being developed to cool waterfront buildings around the world. A $100 million air conditioning system, which will harness cold seawater from the surrounding ocean, now under development, could reach about 65 buildings in downtown Honolulu, including several state office buildings. [39]

At the Purdy's Wharf office and commercial complex, in Halifax, Canada, a new cold seawater cooling system was adopted in 2004. Cold seawater is drawn from the harbor floor, circulated through titanium heat exchangers in the basement of the Wharf building, and then returned to the ocean floor. The building's cooling water is chilled by the seawater in the heat exchangers, and then pumped throughout the building.

This type of seawater cooling system consists of two main loops. In the first loop, centrifugal pumps draw cold seawater from the bottom of the harbor, and then circulate the seawater through heat exchangers that are located in the basement mechanical room of the building to be cooled. The warmed

39. The Associated Press, *Hawaii eyes ocean-based cooling,* http://ithacajournal.com/news/stories/20050407/lifestyle/2107298.html, (accessed April, 2005)

seawater is then returned to the harbor floor. The second loop carries the building's cooling water. In the heat exchanger, this water is chilled as heat is transferred to the seawater. A pump then circulates the chilled water throughout the building.[40] Finally, cool air is delivered to each floor by an air circulation fan that moves the warm building air through a cooling coil that is part of the cooling water loop. To minimize pumping costs, the seawater pumps are located as close to the seawater level as possible.

Purdy's Wharf sea water cooling system.

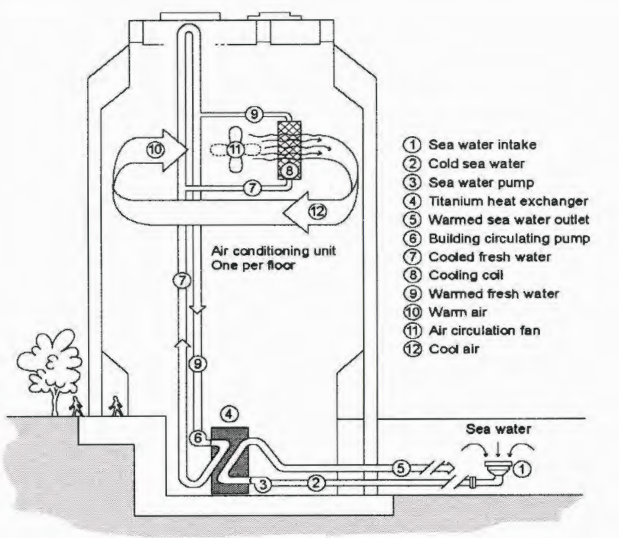

Figure 16, Conceptual sea water cooling system. (Source: Natural Resources, Canada, *Seawater Cooling System for Buildings*, http://oee.nrcan.gc.ca/Publications/infosource/Pub/ici/caddet/english/R118.cfm?text=N&printview=N [accessed October, 2004])

40. Natural Resources, Canada, *Seawater Cooling System for Buildings*, http://oee.nrcan.gc.ca/Publications/infosource/Pub/ici/caddet/english/R118.cfm?text=N&printview=N (accessed October, 2004)

Design Solution

The design of the temporary ferry terminal represents my understanding of sustainable design both in concept and practice. The current design is supposed to well respond to the challenges I stated earlier in Chapter 1: the short life-span of the building; the impact of building process, construction & demolition waste; and indoor environmental quality. The design also respects the natural elements, such as water, sunlight, wind, and air.

Structure

The structure is a fabric tensile structure. Compared to a conventional steel truss or concrete frame system, which would use thousands of tons of materials in this ferry terminal, tensile structure requires by far the least material consumption. The physical properties of tension make the structural components the most efficient, in which every part is working to maximum efficiency.

Both PVC-coated membrane and PTFE-coated glass fiber are suitable for the roof of this project. The City of Shenzhen has several local businesses that can manufacture various architectural membranes. Local material will lower the energy consumption and cost in transportation. PVC-coated membrane will be built faster than PTFE-coated covers and with less cost; however, PVC-coated membrane requires more cleaning maintenance and lasts only about 15 years, which means the whole roof covering can satisfy the complete journey for this temporary terminal. But it can not be moved to another site for use in another new construction after that, instead, the PVC materials have to be recycled.

With fabric tensile structure's high capability to present infinite double-curved free flowing shapes, only imagination is limitation. The form in my design is the terminal's response to the surrounding costal landform, where many mild hills and islands enrich the horizontal view of ocean. The form of the building tries to integrate its profile into surrounding skylines.

The whole structure covers long span area as 360' by 210' with only four masts erecting in the building. Such structure also renders the building with high flexibility for interior rearrangement when needed without compromising the functional demands. Overhanging fabric roof casts shadow for passengers entering and leaving the terminal.

Site and water

The current site for this temporary terminal is used as a concrete bulk yard, a brown field, where storm water carrying sediments, automotive fluids, and solid wastes directly flows into the South China Sea. Wiyout a doubt, the new ferry terminal will increase the traffic load in this area. So an environmentally responsible parking lot plays a significant role in controlling environmental impacts.

Shenzhen Airport began to adopt grass paving in its parking lot. The grass paving has appearance of grass, as well as the load bearing capability for parking. Grass paving also does a great job in absorbing storm water in parking lot so to resuce runoff. The same pattern of grass paving in the airport terminal parking lot will be used to indicate the relationship between the airport and the ferry terminal.

The form of the ferry terminal roof not only serves as a landmark welcoming passengers; but it wull also be crucial to indoor climate control and water savings. Four concaves of the roof keep the balance of the structure with convexities; meanwhile, they will add extra benefit in rainwater collection and storm water reduction. Instead of flowing on the ground and into the sea, rainwater flows down into four interior pools, which serve as rainwater tanks. When tanks are full, extra rainwater can go to sewer pipes and be stored for landscape irrigation. On hot days, water in four pools can be sprayed on to roof by a simple spraying fixture. When the water flows back, it will absorb heat on the roof and reduce the cooling load inside the building.

Container

The site is a mixed-use port, where hundreds of containers are shipped in and out every day. Several bulk yards were built for containers storage. A standard container's size is 20' or 40' long, 8'6" wide and 8'6" high. Such dimension is similar to typical railway carriage and bigger than most office workstations. In my design, containers are modified as standard units for office, bathroom, and duty-free stores. If needed, several containers can also assemble a bigger space, such as a conference room.

Figure 17, Containers on site


Figure 18, Container Handler

The specific site provides opportunities to build more with less in an unconventional way. Onsite modified standard containers can be used as office units and small rooms for various needs. In this way, this temporary terminal minimizes the demand for conventional energy-intense materials such as concrete and steel. The process of container modification is simple and quick. Onsite container handlers are able to move and assemble the containers for interior spaces. No additional heavy construction equipment is needed. For a typical container room, the only thing one needs to do is to remove the doors at both ends of the container, and replace them with operable windows, doors, and louvers. Several additional openings are cut in some containers' sides, and such containers are assembled together to achieve several larger spaces than a standard unit.

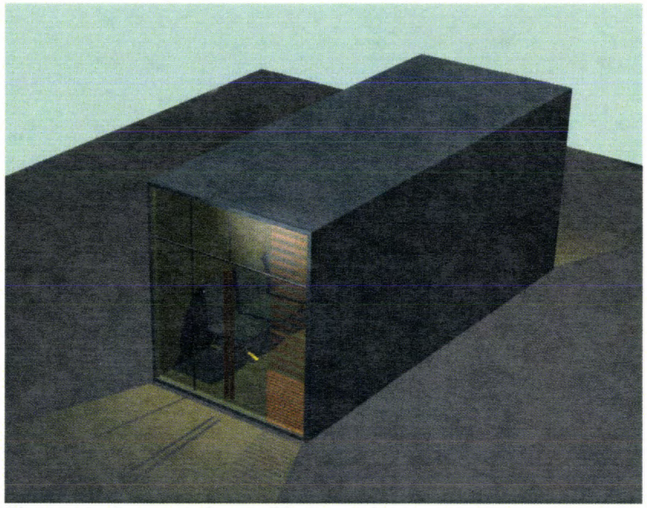

Figure 19, Concept of a modified container

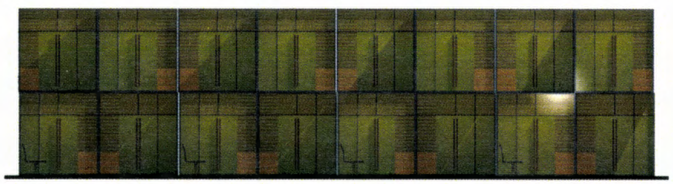

Figure 20, Concept of piled containers

Design Solution

Plan and Circulation

Modified containers not only significantly reduce the resource consumption of the project; they also define and reinforce the building's circulation. The current layout divides the plan into three main areas: arrival, departure, and atrium.

Passengers in the arrival and departure areas need to line up and be inspected for necessary documents at each side's checkpoints. The current layout of the interior space reinforces the spatial identification, and indicates to passengers the direction of linear circulation. The atrium is enclosed by containers. It hosts people and refreshes them with duty-free stores and food services. Compared to the busy atmosphere in checkpoints, the steps rhythm in this atrium is more relaxed. Due to the security requirement, the atrium, with its surrounding containers, also separates the whole building into two parts to prevent passengers going across the border without inspection.

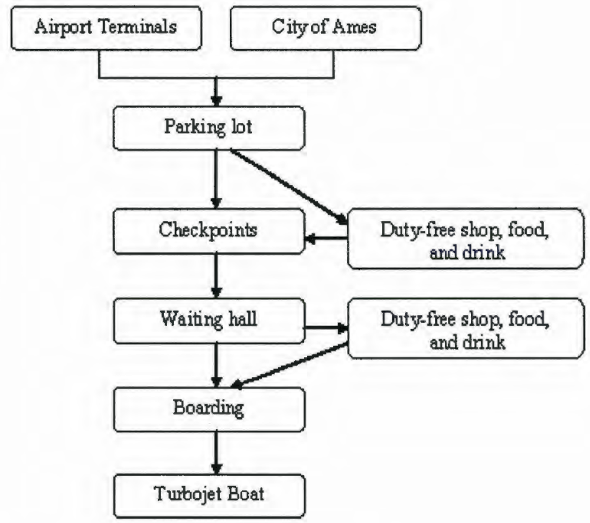

Diagram 1, Circulation of departure

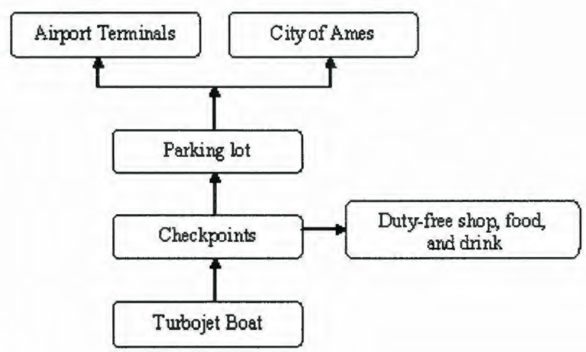

Diagram 2, Circulation of arrival

Indoor environmental quality

Shenzhen and Hong Kong suffered extremely under Severe Acute Respiratory Syndrome (SARS) in 2003. At that time, entering public spaces like a terminal was nearly a nightmare for people who had to travel. Mechanical central air-condition systems were later widely thought to help spread deadly airborne particulates. Energy-greedy mechanical cooling systems are supposed to make people more comfort. But ironically, they often make things worse. Conventional buildings have enormous unredeemable energy costs in HVAC, however, sometimes they end up with poor indoor environmental quality.

The form of the ferry terminal's structure helps to improve the indoor climate control. Five convexity openings in the roof serve as five waster-air chimneys to facilitate air circulation by pulling and expelling waste-air and take in fresh air. The shape of structure helps warm and waste air rise along the roof. Improved ventilation will improve the comfort even under higher temperatures, thus decreasing the demand for cooling in the summer.

The whole space underneath the fabric canopy is bathed in a pleasant diffused light. Background lighting is unnecessary during the daytime. When in the hot summer, sprayed out water flows back into four interior pools, the pools' ripples along with sea waves besides the building reflect highlight to the otherwise peaceful roof.

Several interior gardens help to define the interior space; meanwhile, they are supposed to improve the visual pleasure and the indoor air quality.

Energy saving, C&DW, and Recycling

Large amounts of unredeemable energy can be saved by using a cold sea water cooling system as discussed earlier in Chapter 2. With fewer heat loads by reducing lighting during daytime, the cooling system can be even more energy efficient. The total building's embodied energy is significantly reduced by adopting a minimalist structure and on-site modified containers. Meanwhile, the architecture form facilitates air flow and is expected to reduce mechanical ventilation load. All these are combined to significantly reduce the building's energy consumption during construction and operation.

The fabric of the roof is prefabricated and prepared outside the site. The construction period will be much faster than conventional concrete or steel structure. The extra material during construction, for example, fabric, can be used for pavilions for pedestrians walking from the parking lot. Unlike concrete construction, the total building envelop construction on-site can be waste water free.

Most plastics are recyclable, but the current rates of recycling are not

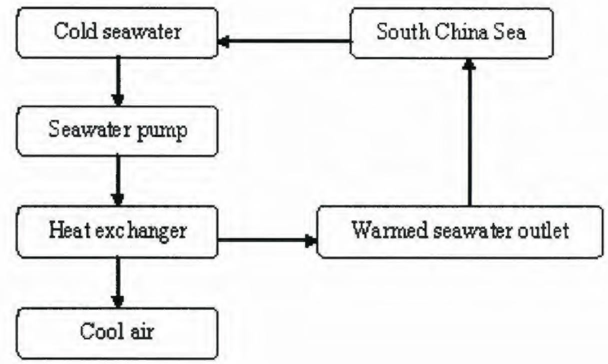

Diagram 3, Conceptual framework of the cold seawater cooling system high because the wide variety of plastics in use makes them difficult to separate. Some plastics such as pure polyvinyl chloride (PVC) would be recycled from buildings more often if designed for easy removal. [41] For the PVC in the fabric terminal, it is very easy to collect and transport fabric to recycle. The current technology can recycle 100% PVC.[42]

As for recycling the containers, doors can easily be assembled back onto the containers to and make them ready to be common containers used for storage and shipping.

41. Rubb, http://www.rubb.com/, (accessed October, 2004)
42. Ibid

Design Solution

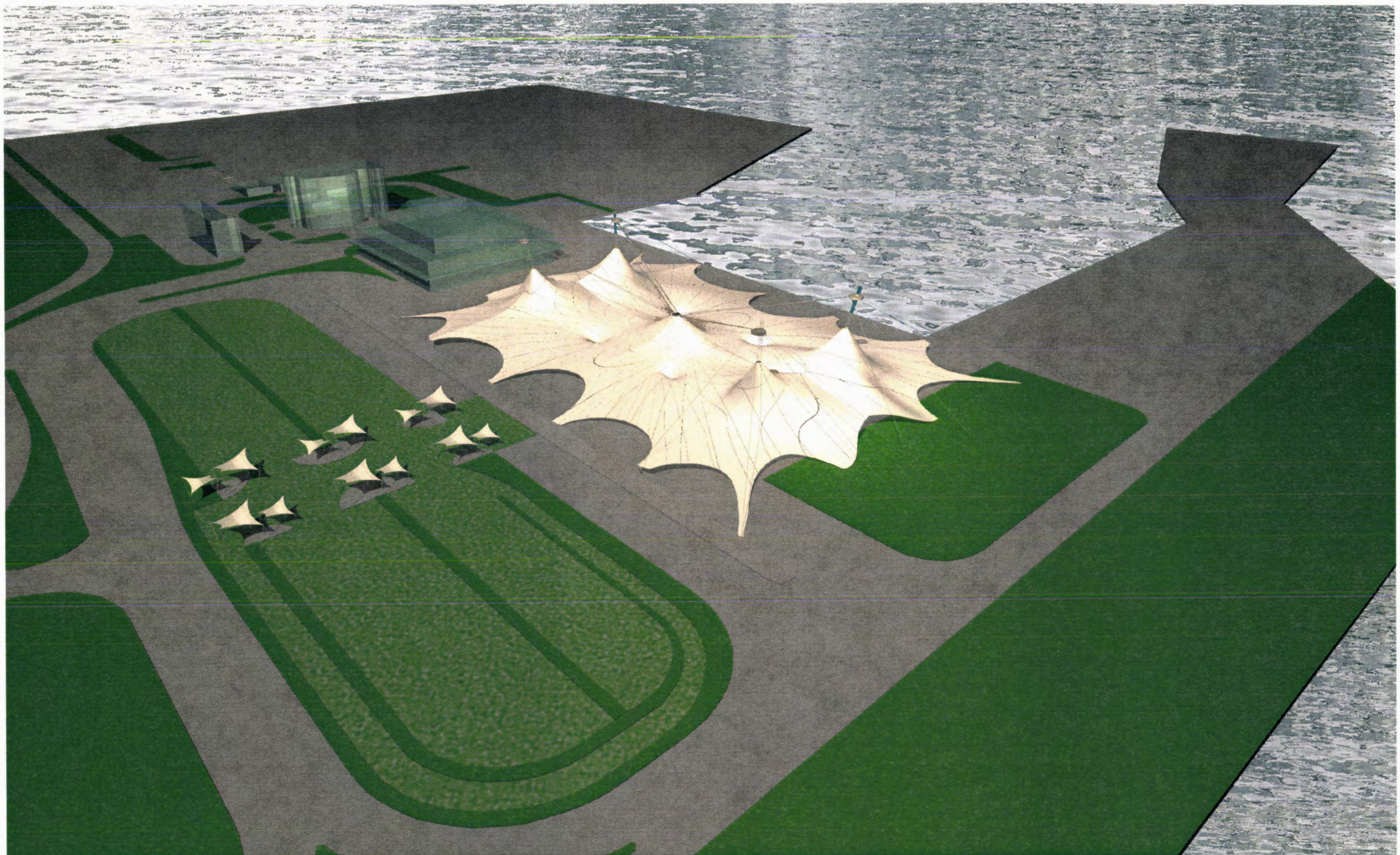

Figure 21. Aerial View

Design Solution

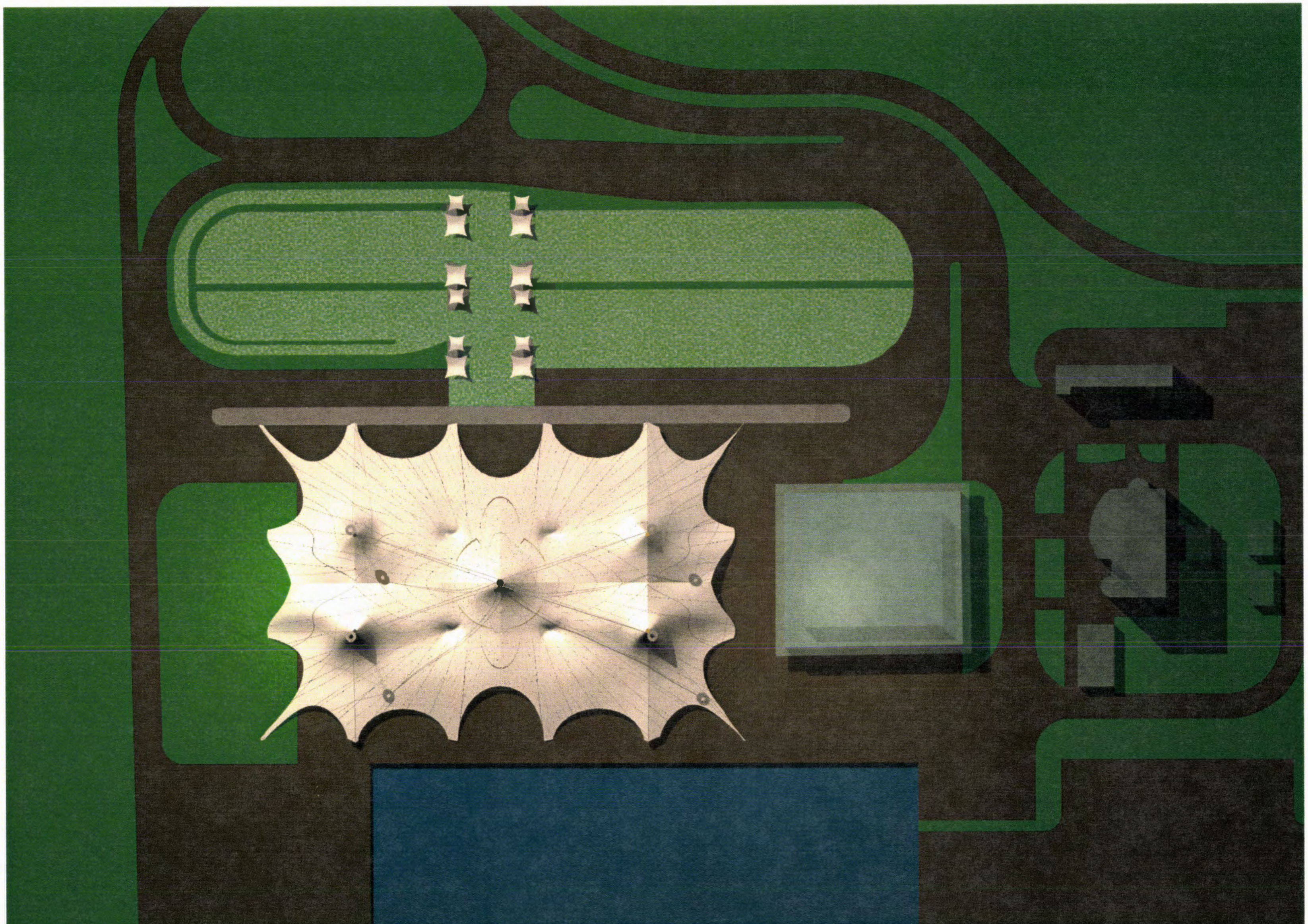

Figure 22. Site Plan

Design Solution

Figure 23. View from Southwest

Design Solution

Figure 24. Waterfront View

Design Solution

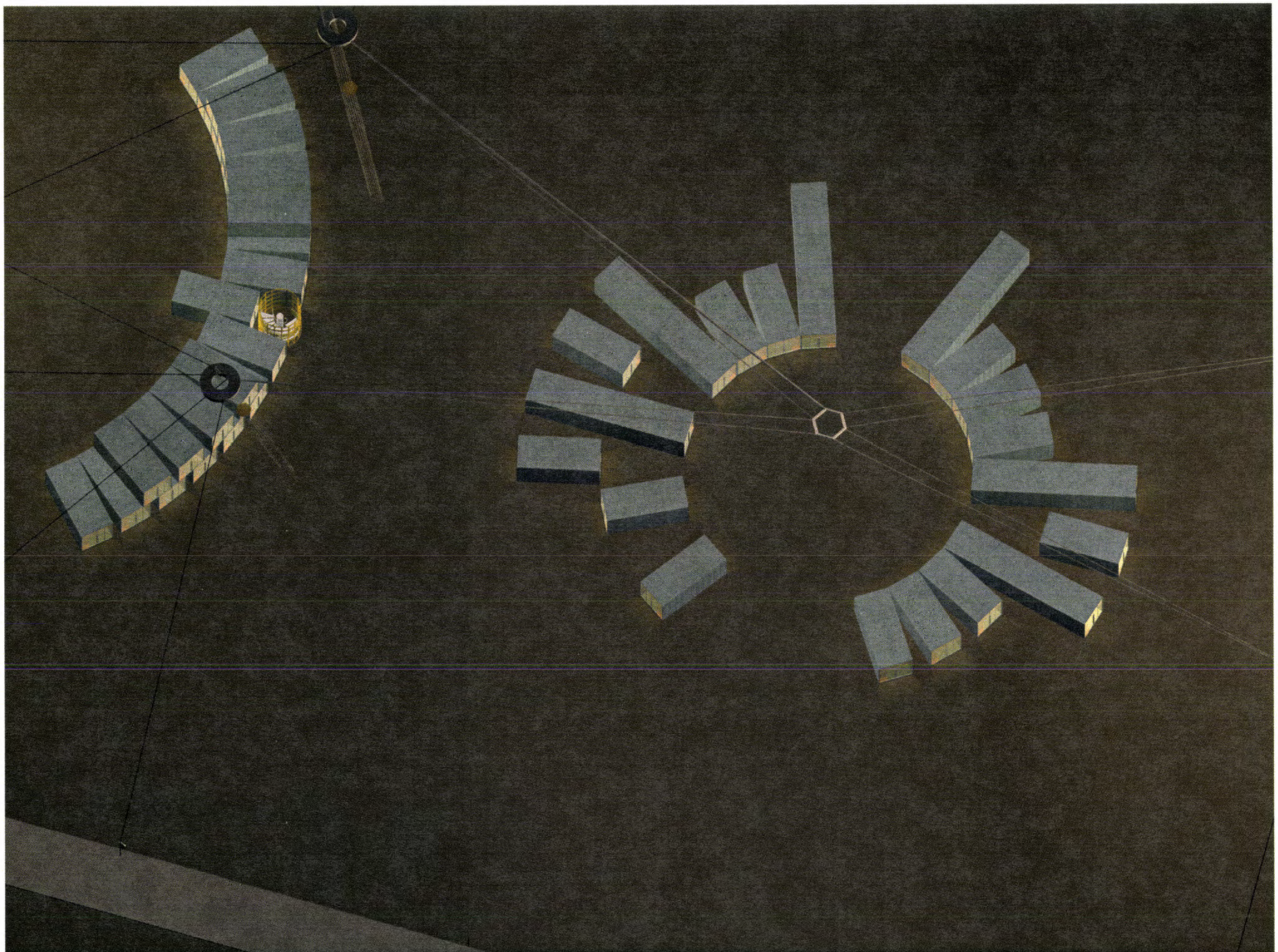

Figure 25. Conceptual interior containers layout

Design Solution

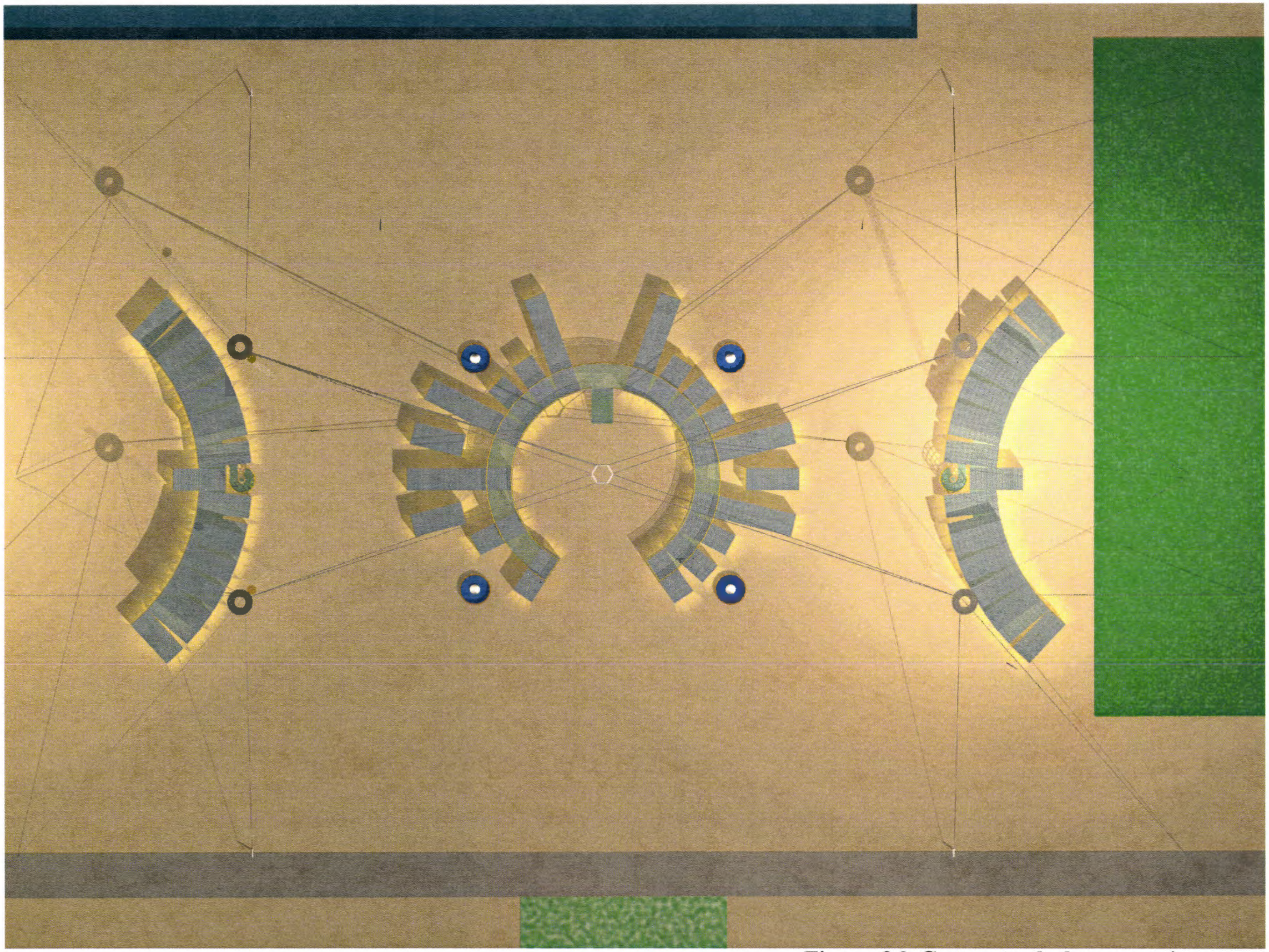

Figure 26. Conceptual plan, containers define the interior space

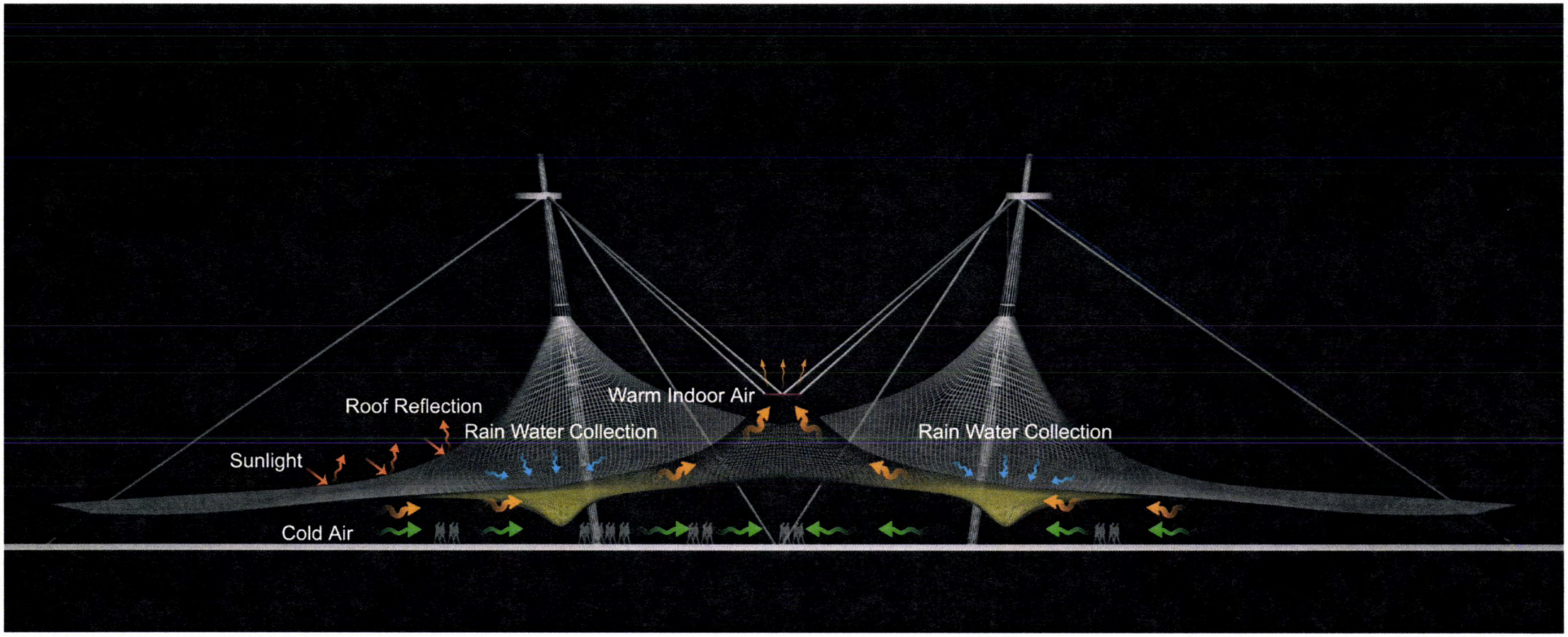

Figure 27. Analysis of roof form and its environmental consideration

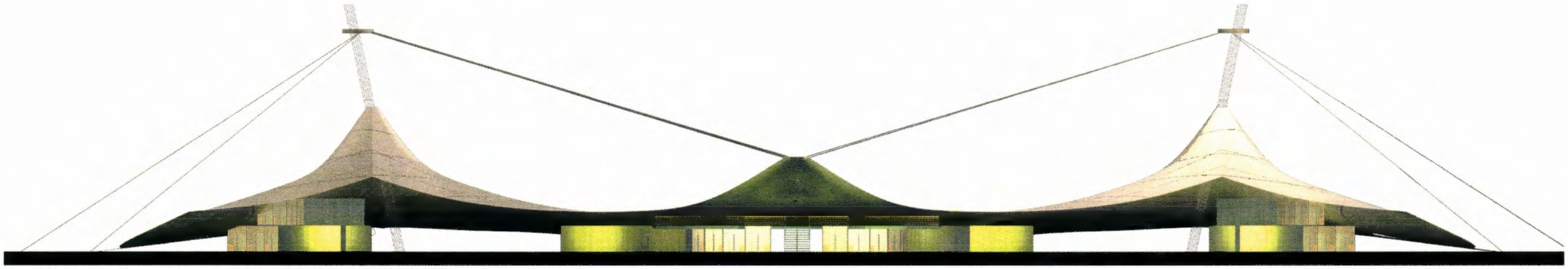

Figure 28. Section 1-1

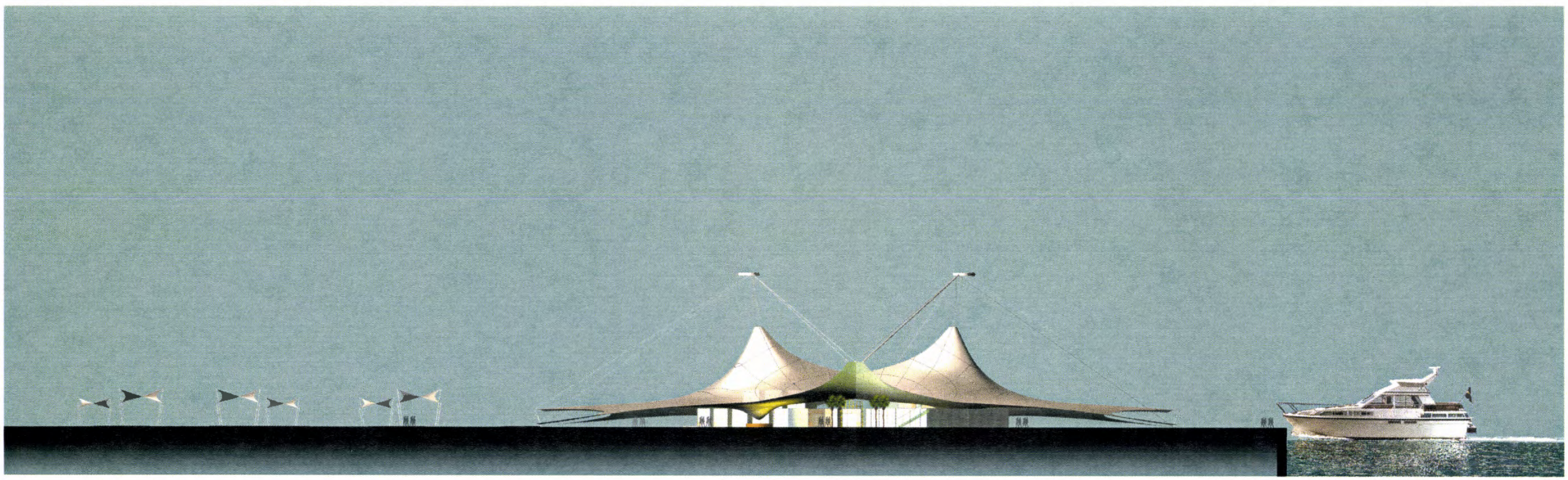

Figure 29. Section 2-2

Design Solution

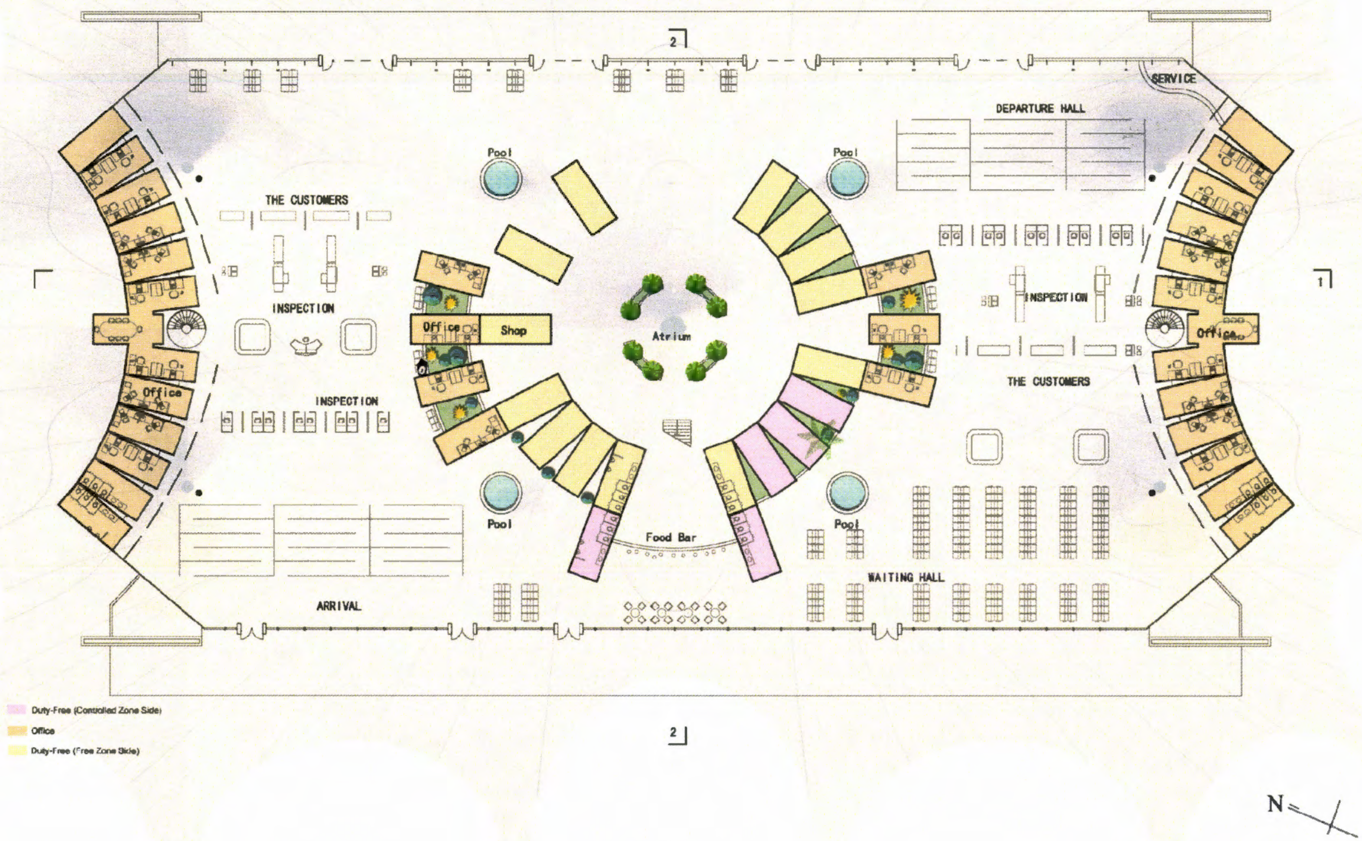

Figure 30. Plan

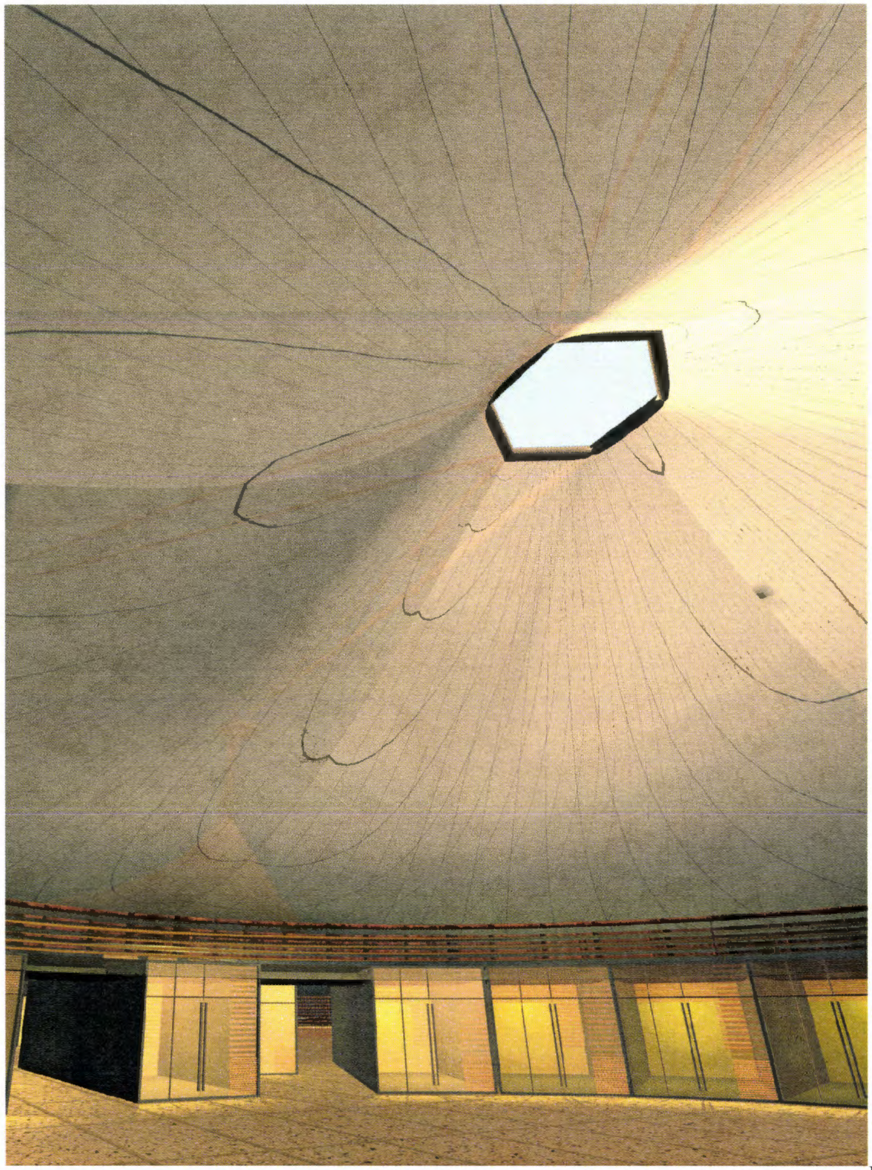

Figure 31. View toward interior atrium

Design Solution

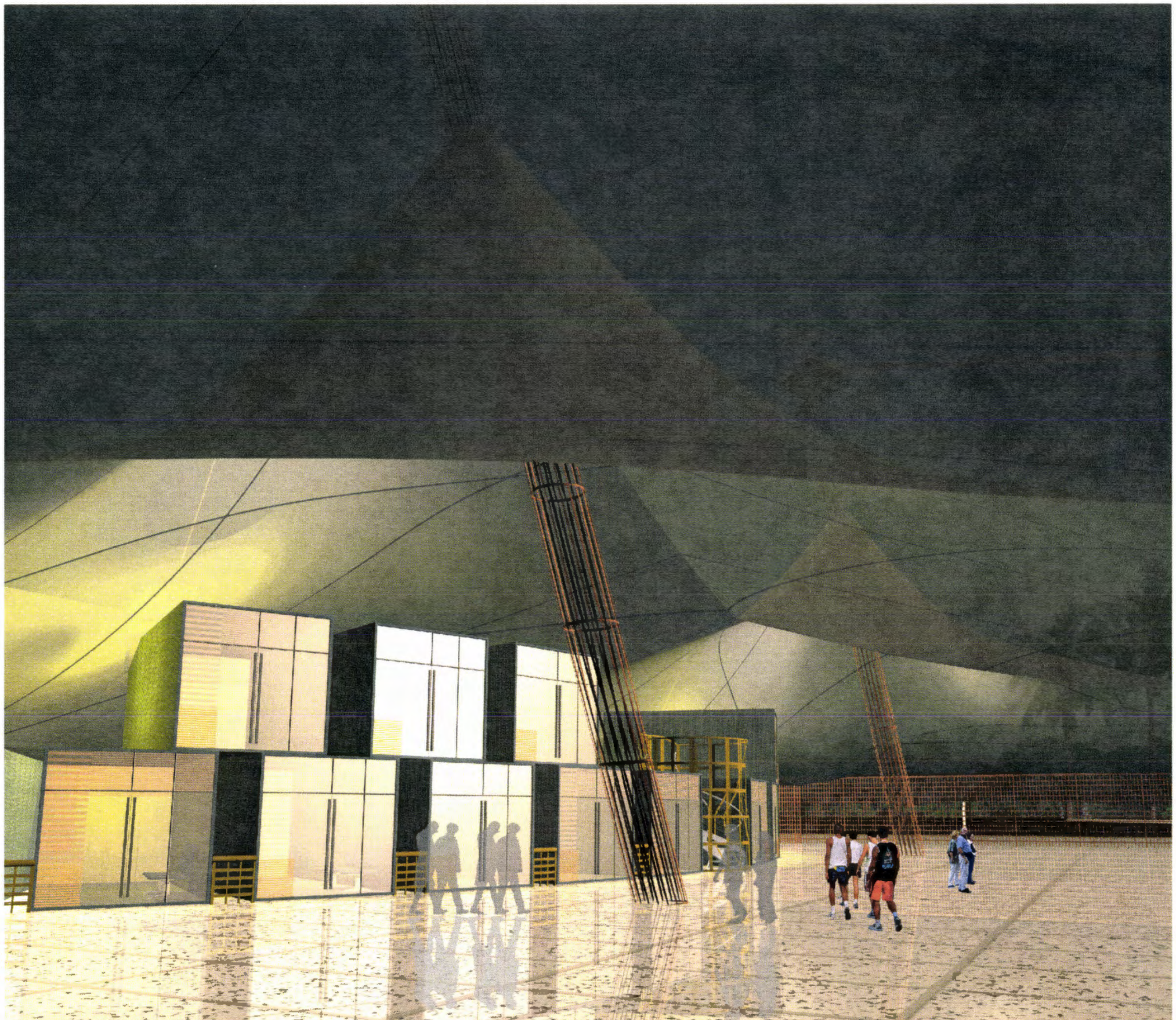

Figure 32. View of interior

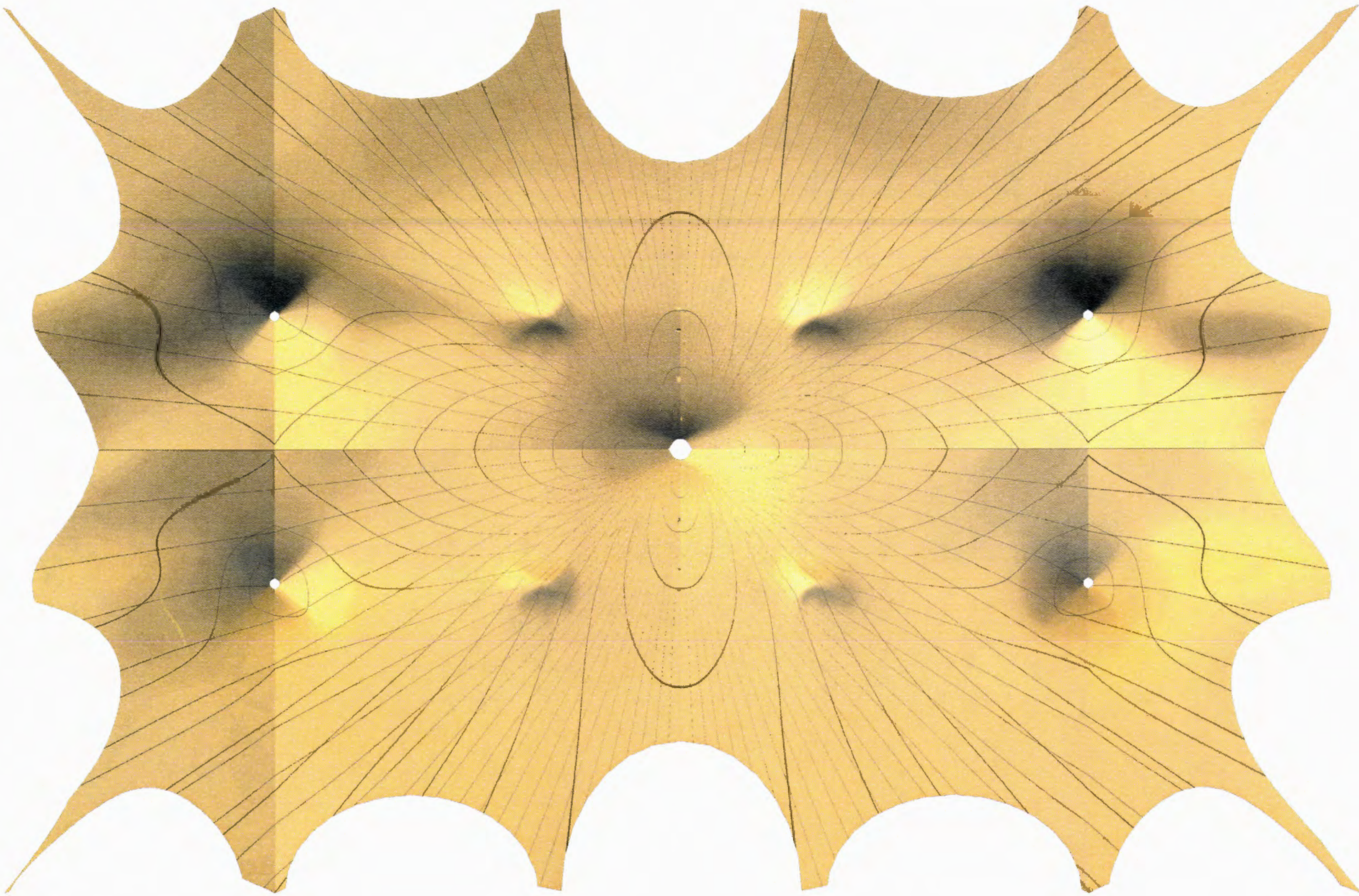

Figure 33. Texture of fabric tensile roof

Conclusion

The general design objectives are aimed at the sustainable development for the whole life-cycle of the temporary building. The design not only stresses energy efficiency, but it also tries to make full response to surrounding environment. The design begins at the study of a bigger environmental context. The consideration of sunlight, water, rain, containers, brown site, and wind, is reflected by the structure, form, materials, and space of the building. On-site modified containers are reminiscent of the relationship between the building and the site.

To build more with less, the design not only minimizes the negative impacts on environment, but also makes the construction and demolition process as quick as possible. Both the fabric membranes and containers are prefabricated, and easy to transport and assemble.

Fabric tensile structure has proved as an excellent building type in hot climates. The translucence cover the interior space and makes the space bathed in diffused natural light. The structure's free flowing shape makes it possible to facilitate natural ventilation, and to collect rainwater by roof. Reduced artificial HVAC system and lighting fixtures can save energy consumption and reduce operation costs.

Overall, the success of the design can be summarized as follows,

Site:

- The building is built on a mixed-use, brown site.
- Stormwater runoff is controlled by grass paving and roof.
- Quick construction reduces site disturbance and environmental impacts.
- The translucence roof reduces light pollution such as glaring issue.
- Bright color fabric roof significant reflects heat, and reduces heat island effect.

Materials:

- Use fabric tensile structure and on-site modified containers. It significantly relieves the environmental burden for such a big project.
- Every part in the roof system is working to the maximum efficiency than most other construction types.

Water:

- Stormwater runoff is controlled.
- Rainwater is collected by the roof. Extra rain water will be preserved for landscape irrigation.
- Sprayed water cools the building by natural process.
- Cold sea water is used for the cooling system.
- A tentative sea water sewer system in bathrooms can be adopted to reduce the usage of clean water.

Energy efficient:

- Speed the building process with prefabricated fabric, and on-site modified containers, which reduce the energy consumption in material production and construction.
- Cold sea water cooling system will reduce the electric burden for building operation.
- Diffused and translucence roof reduces the electric consumption for lighting.
- The Form of the building facilitates natural ventilation, thus to

reduce the mechanical ventilation consumption.

Indoor environmental quality:

- Natural ventilation is facilitated by the form of roof.
- Natural light is optimized by diffused translucence roof.
- Interior gardens improve the visual delight as well as improve the air quality.
- Diffused roof reduces the interior glaring problem.

The design reveals that even a building with a short term life-cycle, like this temporary ferry terminal, can also achieve significant environment benefits when the building fully responds to the environment. A sensitive environmental consciousness is essential for a sustainable designer. Climate, site, water, energy, material, and indoor environmental quality should have their voice be listened to throughout the design process.

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Appendix

Project Checklist

Sustainable Sites

14 Possible Points

Y	Prereq 1	**Erosion & Sedimentation Control**	Required
Y ? N	Credit 1	**Site Selection**	1
Y ? N	Credit 2	**Urban Redevelopment**	1
Y ? N	Credit 3	**Brownfield Redevelopment**	1
Y ? N	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
Y ? N	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
Y ? N	Credit 4.3	**Alternative Transportation**, Alternative Fuel Vehicles	1
Y ? N	Credit 4.4	**Alternative Transportation**, Parking Capacity	1
Y ? N	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
Y ? N	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
Y ? N	Credit 6.1	**Stormwater Management**, Rate and Quantity	1
Y ? N	Credit 6.2	**Stormwater Management**, Treatment	1
Y ? N	Credit 7.1	**Heat Island Effect**, Non-Roof	1
Y ? N	Credit 7.2	**Heat Island Effect**, Roof	1
Y ? N	Credit 8	**Light Pollution Reduction**	1

Water Efficiency

5 Possible Points

Y ? N	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
Y ? N	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
Y ? N	Credit 2	**Innovative Wastewater Technologies**	1
Y ? N	Credit 3.1	**Water Use Reduction**, 20% Reduction	1
Y ? N	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Energy & Atmosphere

17 Possible Points

Y	Prereq 1	**Fundamental Building Systems Commissioning**	Required
Y	Prereq 2	**Minimum Energy Performance**	Required
Y	Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
Y ? N	Credit 1	**Optimize Energy Performance**	1–10
Y ? N	Credit 2.1	**Renewable Energy**, 5%	1
Y ? N	Credit 2.2	**Renewable Energy**, 10%	1
Y ? N	Credit 2.3	**Renewable Energy**, 20%	1
Y ? N	Credit 3	**Additional Commissioning**	1
Y ? N	Credit 4	**Ozone Depletion**	1
Y ? N	Credit 5	**Measurement & Verification**	1
Y ? N	Credit 6	**Green Power**	1

LEED

Materials & Resources

13 Possible Points

Y	Prereq 1	**Storage & Collection of Recyclables**	Required
Y ? N	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
Y ? N	Credit 1.2	**Building Reuse**, Maintain 100% of Shell	1
Y ? N	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
Y ? N	Credit 2.1	**Construction Waste Management**, Divert 50%	1
Y ? N	Credit 2.2	**Construction Waste Management**, Divert 75%	1
Y ? N	Credit 3.1	**Resource Reuse**, Specify 5%	1
Y ? N	Credit 3.2	**Resource Reuse**, Specify 10%	1
Y ? N	Credit 4.1	**Recycled Content**, Specify 5% (p.c. + 1/2 p.i.)	1
Y ? N	Credit 4.2	**Recycled Content**, Specify 10% (p.c. + 1/2 p.i.)	1
Y ? N	Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
Y ? N	Credit 5.2	**Local/Regional Materials**, of 20% in MRc5.1, 50% Harvested Locally	1
Y ? N	Credit 6	**Rapidly Renewable Materials**	1
Y ? N	Credit 7	**Certified Wood**	1

Indoor Environmental Quality

15 Possible Points

Y	Prereq 1	**Minimum IAQ Performance**	Required
Y	Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
Y ? N	Credit 1	**Carbon Dioxide** (CO_2) **Monitoring**	1
Y ? N	Credit 2	**Ventilation Effectiveness**	1
Y ? N	Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
Y ? N	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
Y ? N	Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
Y ? N	Credit 4.2	**Low-Emitting Materials**, Paints	1
Y ? N	Credit 4.3	**Low-Emitting Materials**, Carpet	1
Y ? N	Credit 4.4	**Low-Emitting Materials**, Composite Wood	1
Y ? N	Credit 5	**Indoor Chemical & Pollutant Source Control**	1
Y ? N	Credit 6.1	**Controllability of Systems**, Perimeter	1
Y ? N	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
Y ? N	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
Y ? N	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
Y ? N	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
Y ? N	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Innovation & Design Process

5 Possible Points

Y ? N	Credit 1.1	**Innovation in Design**	1
Y ? N	Credit 1.2	**Innovation in Design**	1
Y ? N	Credit 1.3	**Innovation in Design**	1
Y ? N	Credit 1.4	**Innovation in Design**	1
Y ? N	Credit 2	**LEED™ Accredited Professional**	1

Project Totals

69 Possible Points

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

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