Centro Migrante: Self-help Housing Community
For Transient Seafarers in Manila

by

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Abstract

The design of sustainable housing in developing countries involves social, economical and technical issues and requires a more global and integrated planning action. In these countries, housing systems need to be designed and planned according to the local and geographical conditions, in order to best meet the requirements of the people in need of shelter. The thesis addresses this issue focusing on a specific project in the Philippines being undertaken by the entrepreneurship initiative Centro Migrante which is addressing the problem of providing housing for transient jobseekers in Manila. The thesis focuses specifically on proposing sustainable solutions for temporary dwellings which are based on detailed research on local materials, techniques and climate conditions. Architectural, structural and bioclimatic principles have been intertwined in a multidisciplinary design context to develop a housing community prototype with multiple requirements: affordability, safety in response to natural hazards (typhoons and earthquakes), energy efficiency and sustainable use of local resources. This technical research has been conducted in collaboration with Centro Migrante team managers in order to ensure that the solutions are feasible and compatible with the global business plan.

Thesis Supervisor: Jerome J. Connor

Title: Professor of Civil and Environmental Engineering

TABLE OF CONTENTS

PART THREE: PROJECT DEVELOPMENT

List of Figures

List of Tables

Acknowledgments

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"A Tradição é um desafio para a Inovação".

"Tradition is a challenge for Innovation"

Alvaro Siza

Introduction: Slum housing problem in developing countries

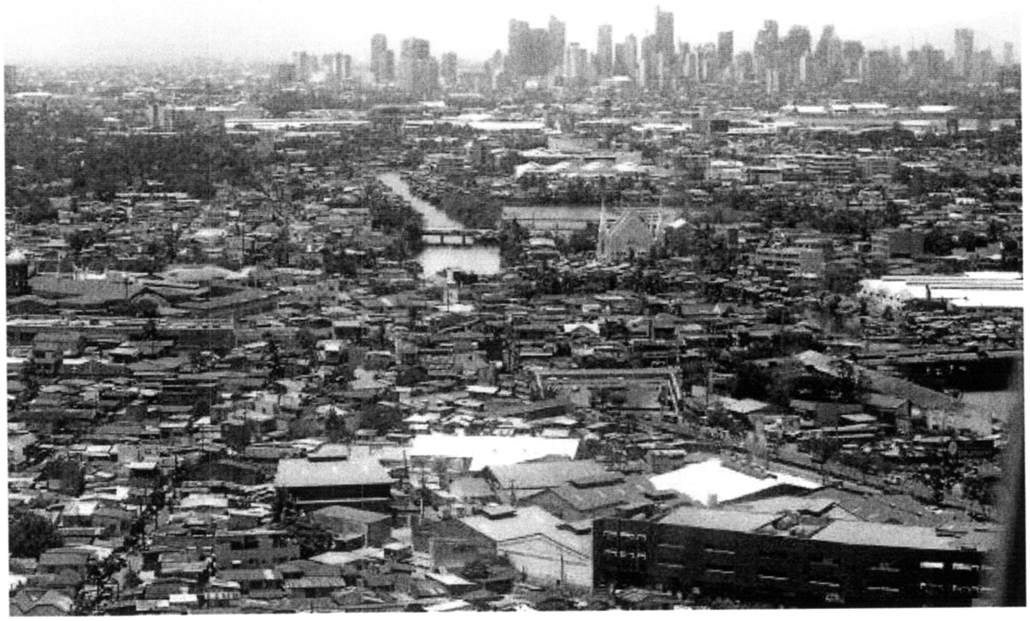
i) Low cost housing in developing countries: social framework

The problem of housing design in developing countries is a major issue, since it involves integrating social, economical and technical issues. Currently, mega-cities in the world are becoming increasingly populated by rural-to-urban migrants, rather than permanent city-dwellers. Most often, failure to address this issue in urban planning is the major reason for the increase in urban poverty and the informal housing, or squatter, sector. In developing countries around the world, it is estimated that more than 200 million people have been driven by poverty to leave their rural hometowns and seek employment in urban areas, where they are usually unable to afford decent shelter while searching for jobs and are being forced to live as squatters on public or private lands.

ii) A specific case: the Philippines Seafarers' job market

The Philippines is the largest source of seafaring labor in the world, supplying over 25% of the world market. The archipelago lies in a highly strategic position for the Southeast Asia shipping industry and, yet, is the only country without an organized seafarers' center or central location for professional networking.

Roughly 1 million Filipinos a year spend months away from their home provinces and in Manila's port areas looking for jobs as seafarers, and they wander all day around many parts of Manila, waiting for the recruitment agencies to approach them for work. This particular economic and social situation multiplies the number of people living in depressed and degrading conditions and increases significantly the extension of slum neighborhoods and squatter shelters. The job search may last several months and, while looking for their first, or next, job contract, most Filipino seafarers cannot afford any other accommodation than undignified shanties. In addition, the particular local climate conditions, with frequent typhoons during the monsoon season, earthquake hazards and the high level of humidity and rainfall, further exacerbate these poor living conditions.



Intro Figure 1 View of Manila Slums

Intro Figure 2 Slum housing in Manila outskirts

Intro Figure 3 Squatter areas in Manila

Intro Figure 4 Homeless people in port areas of the city

iii) Centro Migrante Initiative: the 100K competition, the prototype Pier One

In response to this unbearable situation, the business initiative Centro Migrante has been proposed and carried out by a group of six Filipinos entrepreneurs. Their project is based on the idea of providing affordable and safe housing to transient jobseekers in Manila, on the basis of self-built community models. This goal will be accomplished by using durable, cost-efficient, and scalable architecture, paired with a self-help program that mobilizes the migrants in building and maintaining their own living conditions. The project won the 2006 edition of the 100K Ideas Competitions. Out of the six Filipinos entrepreneurs, five are affiliated with MIT, Artessa Saldivar-Sali (Design & Infrastructure Manager), Illac Diaz (CEO and COO), Neil Ruiz (Government and Corporate Relations), Chester Yu (Support Service), Tina Laforteza (Strategy & Business Development), while Bianca Lotsin (Real Estate Acquisitions/Legal Affairs) is a J.D. from Yale.

The basic idea of Centro Migrante lies in the self-help housing concept: in this perspective, they propose a business model based on people self-building and self-maintaining their shelters. A prototype of this idea has been running since 2003, and it has successfully shown profitability and has already helped 80,000 Filipinos. The pilot shelter, called Pier One, was built in Intramuros, the ancient Spanish neighborhood in Manila and represented a good market test for the self-help housing model.

Intro Figure 5 Pier One Dormitory[1]

[1] Courtesy of Centro Migrante Inc.

After four years, Pier One has grown into a 400-bedroom dorm. Another branch in Padre Faura, with a 100-bed capacity, opened recently. For only 100 PH pesos a day, seafarers are provided clean bedrooms, dining quarters, laundry and bathroom areas. They also get job-matching services, seminars, and temporary jobs while staying at the dorm

Following the initial idea, Centro Migrante makes a further step forward. It proposes a build-for-stay system wherein tenants will be given the option to construct the units from prefabricated parts in exchange for a period of free occupancy. There will also be a work-for-stay system where those without money may sign up for temporary jobs. Also, Centro Migrante aims to realize a different architectural project, in order to increase the sustainability features and decreasing the initial costs.

iv) Research Objectives: the need for a complete project

The team's need for a new complete project has been the starting point of this research. The architectural and engineering planning process of Centro Migrante is the core of this work and not only does it aim to offer a technical solution to Centro Migrante specific needs but also to put forward a model of sustainable community, planned according to integrated design criteria.

The main conceptual idea behind this research is the fact that, in developing countries, housing systems should be designed and planned according to the local and geographical conditions, in order to best meet the needs of the people in need of a shelter. Architectural, structural, urban and environmental concepts should be brought together and integrated in a complex design process which can provide safe, efficient and affordable housing. Centro Migrante idea and future realization offers a response to this affordable housing need and it will represent an important prototype that could be expanded in further directions for seafaring populations in other countries and for migrant populations of other professions. A specific site for the project has been identified in the area of Intramuros (the ancient historical Spanish neighborhood) in Metro Manila, and the research objective is the development of a technical prototype solution to match the concepts and objectives outlined in Centro Migrante's business plan.

v) Research Methodology

The research has been structured in a multidisciplinary approach; architectural, structural, urban and sustainable requirements and solutions are integrated into a global planning action. This conceptual framework is meant to strongly tie the design to construction issues, tailoring the choice of building systems and materials to the most appropriate design/build configuration for modular, design-for-disassembly low cost housing for transient seafarers in Manila. In this perspective, a holistic design approach of integration between the natural environment and the local manmade context has been applied. Centro Migrante is a project "shaped" by its natural environment, coupled with an intense study of local traditions and construction techniques, available indigenous materials and resources. Therefore, while the natural environment poses the main structural and energy efficiency constraints and Centro Migrante business plan poses the architectural and economic constraints, the examples of vernacular architecture, coupled with modern and appropriate technologies, can be elaborated into a suitable design solution.

The work has been divided into three main phases: Project Background, Conceptualization, and Development. The Background phase will include data and information collection about the natural and built environments of the Philippines, in order to establish a "space of action". In the Project Conceptualization phase, all the main constraints posed by the natural and built environment will be evaluated and framed into a specific conceptual approach; in the Development phase, a detailed design scheme will be created, with a deep study of building systems, connections and assembly techniques. The appendices offer some deeper insights into selected topics and complete the research work.

PART ONE:

PROJECT BACKGROUND

CHAPTER 1

1 The Natural Environment: the Philippines in the Southeast Asia region

1.1 Country General Data

Named after Philip II, Prince of Asturia, in 1521, The Philippine Islands became a Spanish colony during the 16th century and so remained for more than three centuries, until they were ceded to the United States in 1898 following the Spanish-American War. The country gained independence only in 1935, when it became a self-governing commonwealth (Kneeland 1883), (CIA 2007).

The Philippines country is located in the Southeast Asia region and it is formed by a series of differently sized islands. According to the information provided by the CIA World Fact Book 2007, they are situated between 5" and 19" N latitude, and between 114" and 125" E longitude, with an extent of about 1,050 miles North-South and 700 East-West. The country total area is 300,000 square kilometers – with land covering 298,170 km^2 and the remaining 1,830 km^2 occupied by water. The archipelago lies between the South China Sea and the Philippine Sea, east of Vietnam and north of Malaysia, at the edge of the North Pacific Ocean and its total coastline equals 36,289 km (CIA 2007)

As for the physical configuration, the terrain is characterized mostly by mountains, with narrow coastal lowlands. The country natural resources are timber, salt, petroleum, nickel, silver, gold, copper and cobalt (CIA 2007).

The country islands are numerous, but only about forty are of any importance; among these Luzon – in which the capital city Manila is situated – is the largest with an area of 350 per 175 miles; after this, the most important are Panay, Mindoro, Cebu, and Mindanao. The political division of the country is set into 73 provinces and 61 chartered cities, with capital city Manila, situated in Luzon Island.

As of July 2007, the population of the Philippines is estimated in 91,077,287 people, with a young median age of 22-23 years (the US average is 36 years) (CIA 2007).

Figure 1-1 The Philippines in the Southeast Asia region[2]

[2] From http://www.lib.utexas.edu/maps

Figure 1-2 Map of the Philippines with its main islands[3]

[3] From CIA World Fact Book 2007.

1.2 *Climatology Information: features of the subtropical climate*

The Philippines archipelago lies in the tropical area of Southeast Asia and its climate resembles that of most Central and South American states: it is a subtropical climate with warm humid conditions, characterized by high average temperatures all year round, high rate of relative humidity and rainfall.

Generally, the temperature range is around 27-30ºC (80-85 ºF), with minimal difference between day and night and fairly constant every month of the year. As for rainfall, it represents the key climatic element in the Philippines. Rainfall distribution throughout the country varies from one region to another, depending upon the direction of the moisture-bearing winds and the location of the mountain systems. Generally, the mean annual rainfall of the country varies from 965 to 4,064 millimeters annually. This high average rate influences also the relative humidity. Detailed tables documenting the climatic data statistics are presented in Chapter 3 for the sustainability requirements assessment.

In addition, the country climate is, more precisely, a tropical monsoon climate, with the northeast monsoon from November to April and the Southwest monsoon from May to October. Therefore, monsoons mark a division into two main periods: the Rainy season, from November to April, and a Dry season, from May to October.

According to the POGASA institute, the Meteorology division of the Philippines Department of Science and Technology (DOST)[4], the dry season may be subdivided further into a cool dry season, from October to February and a hot dry season, from March to May. Also, the same Institute proposed the most accepted division of the country climate in four different subtypes, according to annual rainfall distribution. The capital city Manila is characterized by Climate Type I, with two clearly different seasons throughout the year.

[4] http://www.pagasa.dost.gov.ph/ PAGASA, Philippines Atmospheric Geophysical and Astronomic Service Administration, division of DOST – Department of Science and Technology of the government.

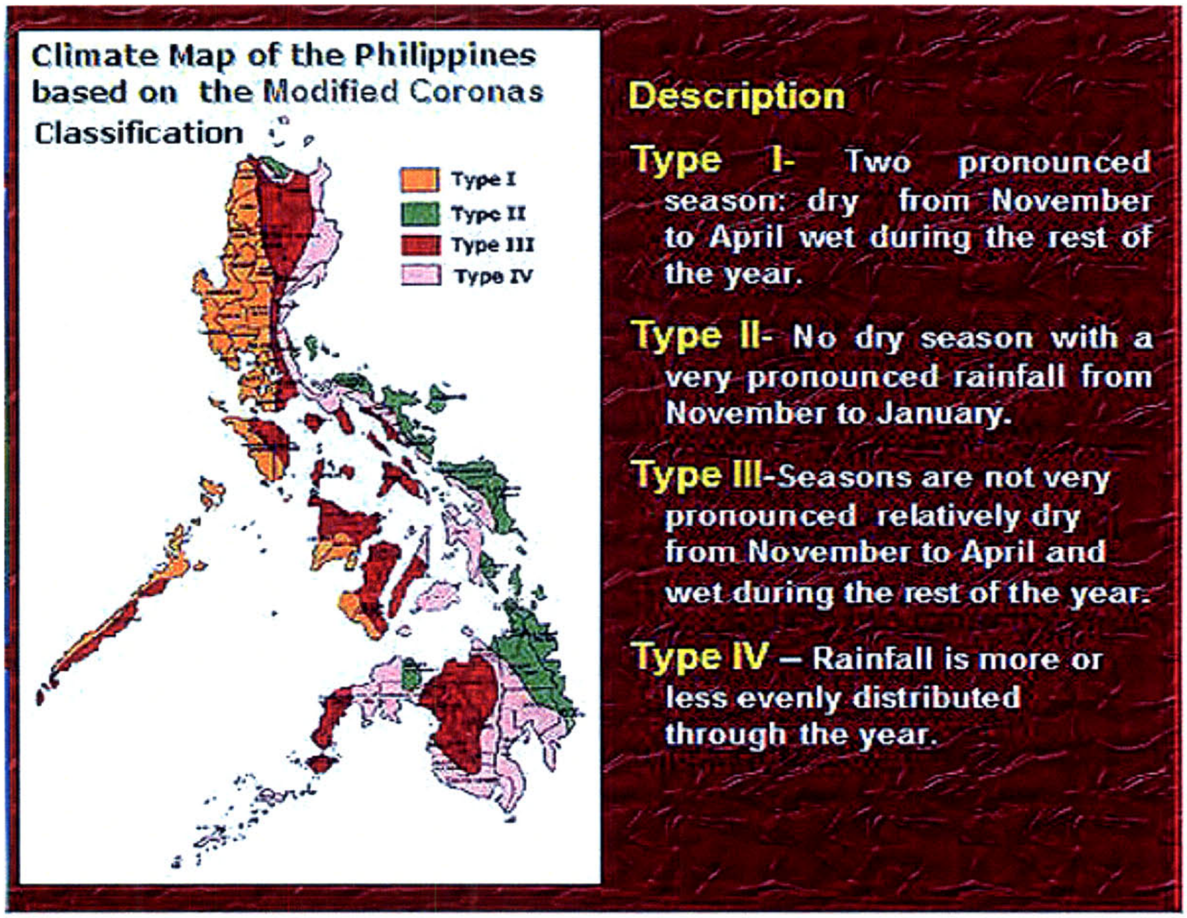


Figure 1-3 Climatic Types Map in the Philippines[5]

1.3 Natural Hazards: a place of extreme events

The Philippines Archipelago lies in a highly sensitive position in the Asian continent, named the Pacific "Ring of Fire" (PacificDisasterCenter 2007) and it is one of the most seismically active and disaster prone areas in the world. Dangerous natural hazards as typhoons, landslides, earthquakes, tsunamis and volcanic eruptions occur very frequently, leading to life losses, homeless people and large damages. In the last decade, the Philippines have suffered severely from natural disasters. In 1990 alone, Central Luzon was hit by both a drought, which truncated hydroelectric power, and by a typhoon that flooded practically all of Manila's streets. Also, that same year, the most damaging event was an earthquake that devastated a wide area in Luzon, and reached a magnitude of 7.8 on the Richter scale.

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[5] From PAGASA Institute, http://www.pagasa.dost.gov.ph/cab/cab.htm

1.3.1 Typhoons and Tropical Storms

Typhoons are the major causes of destruction in the Philippines, due to their high frequency in the area. The country is located astride a storm belt and it is usually affected by 15 storms and struck by at least five typhoons per year (CIA 2007). Typhoons, the south-east Asia equivalent of hurricanes, occur during the Southeast Monsoon season – from June to September – and they bring heavy rain and strong winds, leading often to flooding and landslide, especially in small town and villages. According to the data available through the Pacific Disaster Center (PacificDisasterCenter 2007), Manila is subjected to 5 to 9 typhoons per year with wind speed up to 210km/h (130mph).

Figure 1-4 Aftermath of Typhoon Mylenio in Manila (2006)[6]

The Pacific Disaster Center provides a highly detailed online Atlas to monitor the hazard index of several locations in the Pacific area: the following figures contain maps elaborated with the PDC Atlas and they show subdivisions of areas according to Storm Intensity index. The index is based upon the average wind speed occurring during a storm or typhoon.

[6] Image available on the Internet – unknown direct source

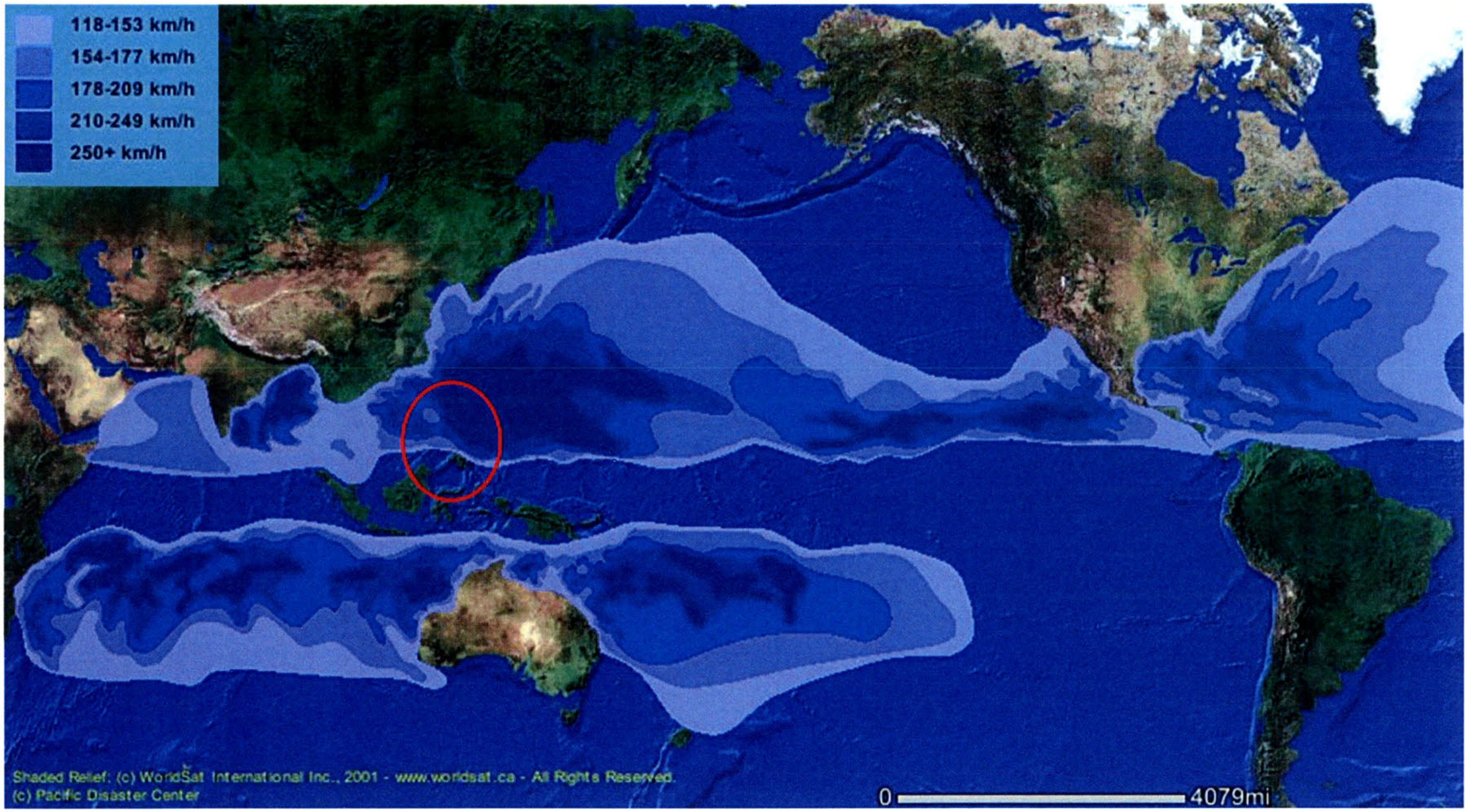

Figure 1-5 Storm Intensity in the Pacific[7]

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[7] *Natural Hazards and Vulnerabilities Atlas* of the Pacific Disaster Center - *www.pdc.org*

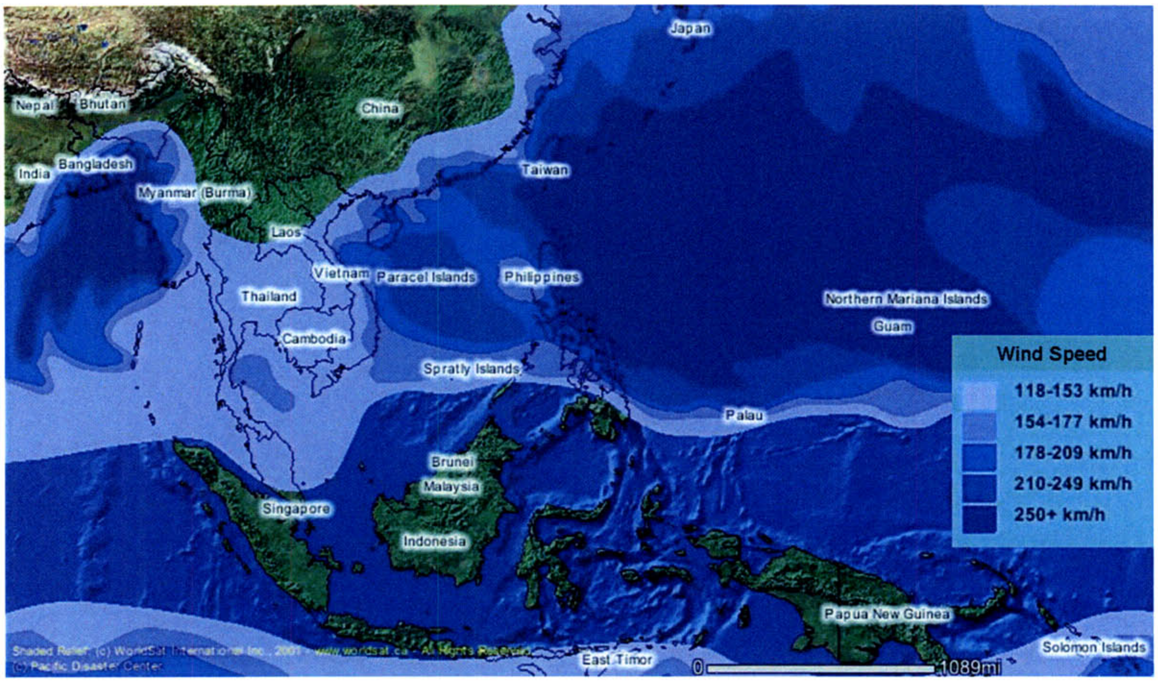

Figure 1-6 Storm Intensity in Southeast Asia[8]

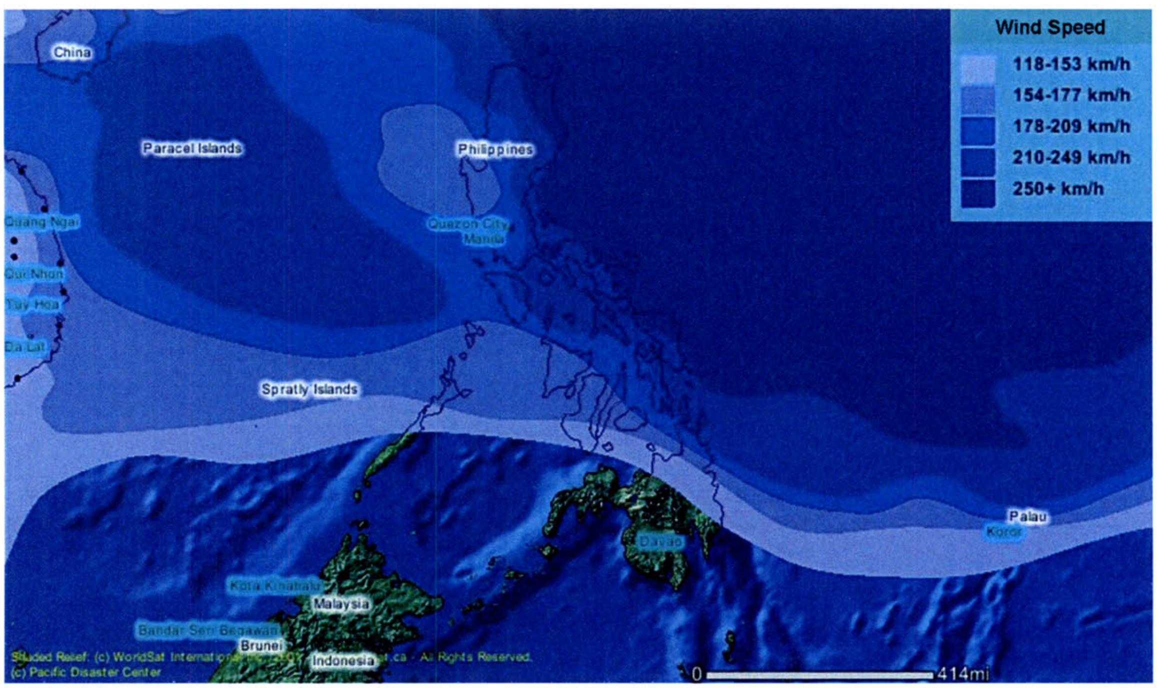

Figure 1-7 Storm Intensity in the Philippines

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[8] The maps in this page have been elaborated with the *Natural Hazards and Vulnerabilities Atlas* of the Pacific Disaster Center - *www.pdc.org*

1.3.2 Earthquakes and Seismic Activity

The Pacific "Ring of Fire", one of the most seismically active areas in the world, has indeed its centre in the Philippines; the archipelago lies in the collision zone of the Eurasian Plate, subducting in the West, and the Philippine Sea Plate subducting in the East. The oblique convergence of the Eurasian and Philippine Sea plates led to the development of the Philippine Fault System and other smaller shallow crustal faults.

The Philippine Fault System is a major strike-slip fault structure that traverses the entire length of the archipelago and characterized the country seismic risk between a M8 and M9. An assessment of the historic seismicity of the Metro Manila area, conducted through the USGS database, showed an impressive record of earthquakes ranging from M5 to M7.8, within a 400 miles range from the capital city.[9] The Philippines Fault has produced several of the most destructive earthquakes in recorded history, including the 1990 Luzon Earthquake (M7.8), which caused an estimated damage of US$2 billions

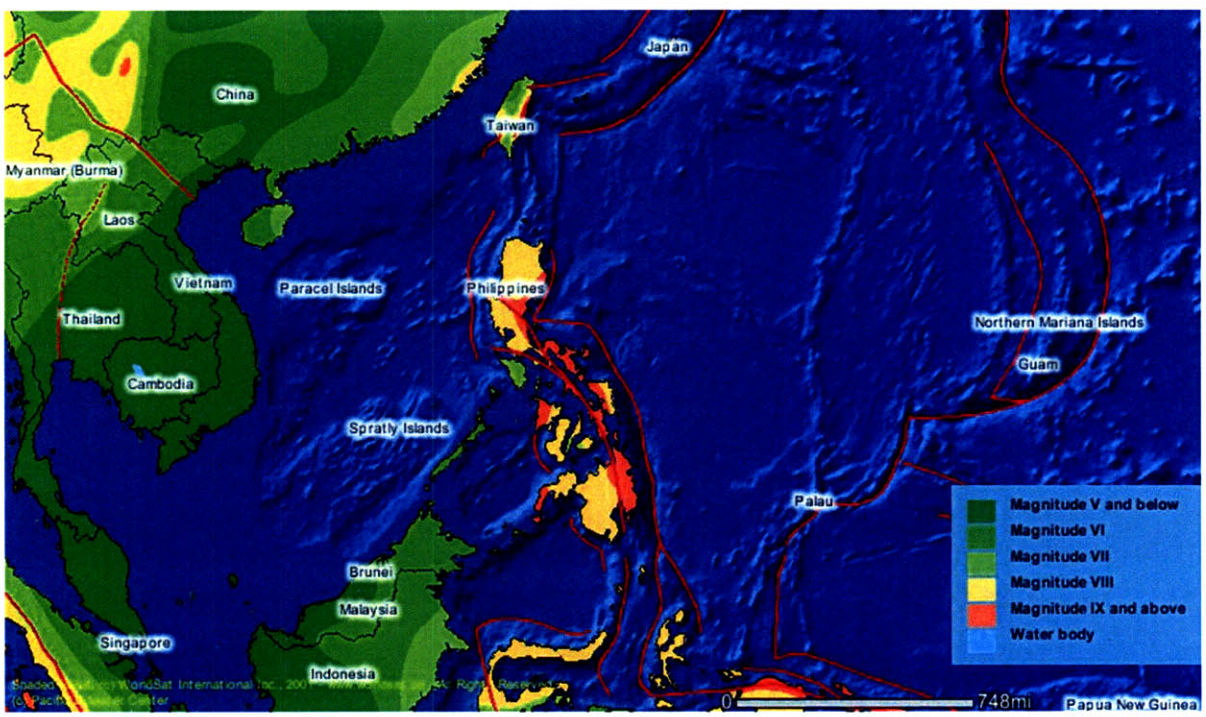

Figure 1-8 Earthquake Intensity Zones[10]

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[9] Complete data are available in Appendix A.

[10] Map elaborated with the *Natural Hazards and Vulnerabilities Atlas* of the Pacific Disaster Center

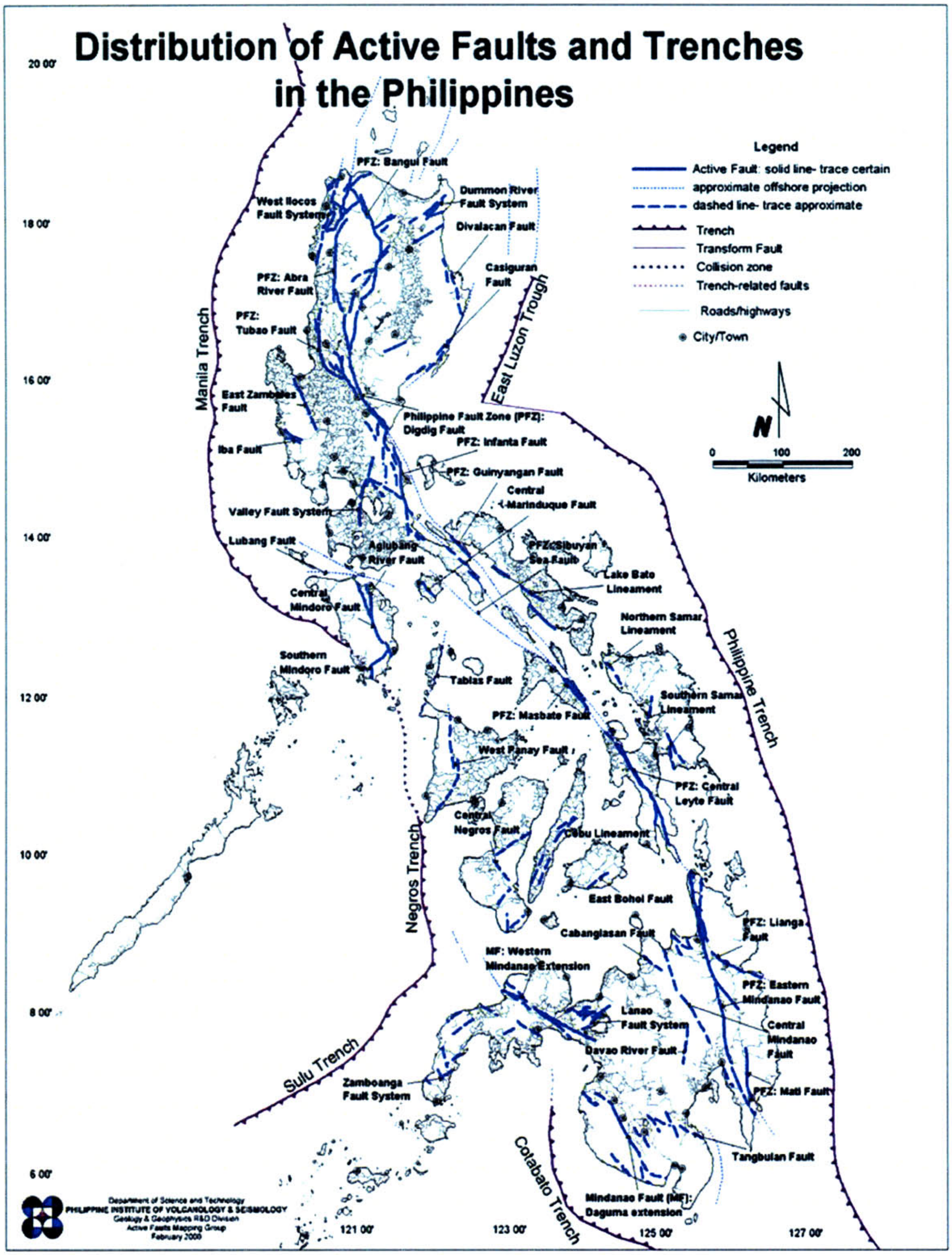

Figure 1-9Active Faults in the Philippines[11]

[11] From the Philippine Institute of Volcanology and Seismology http://www.phivolcs.dost.gov.ph

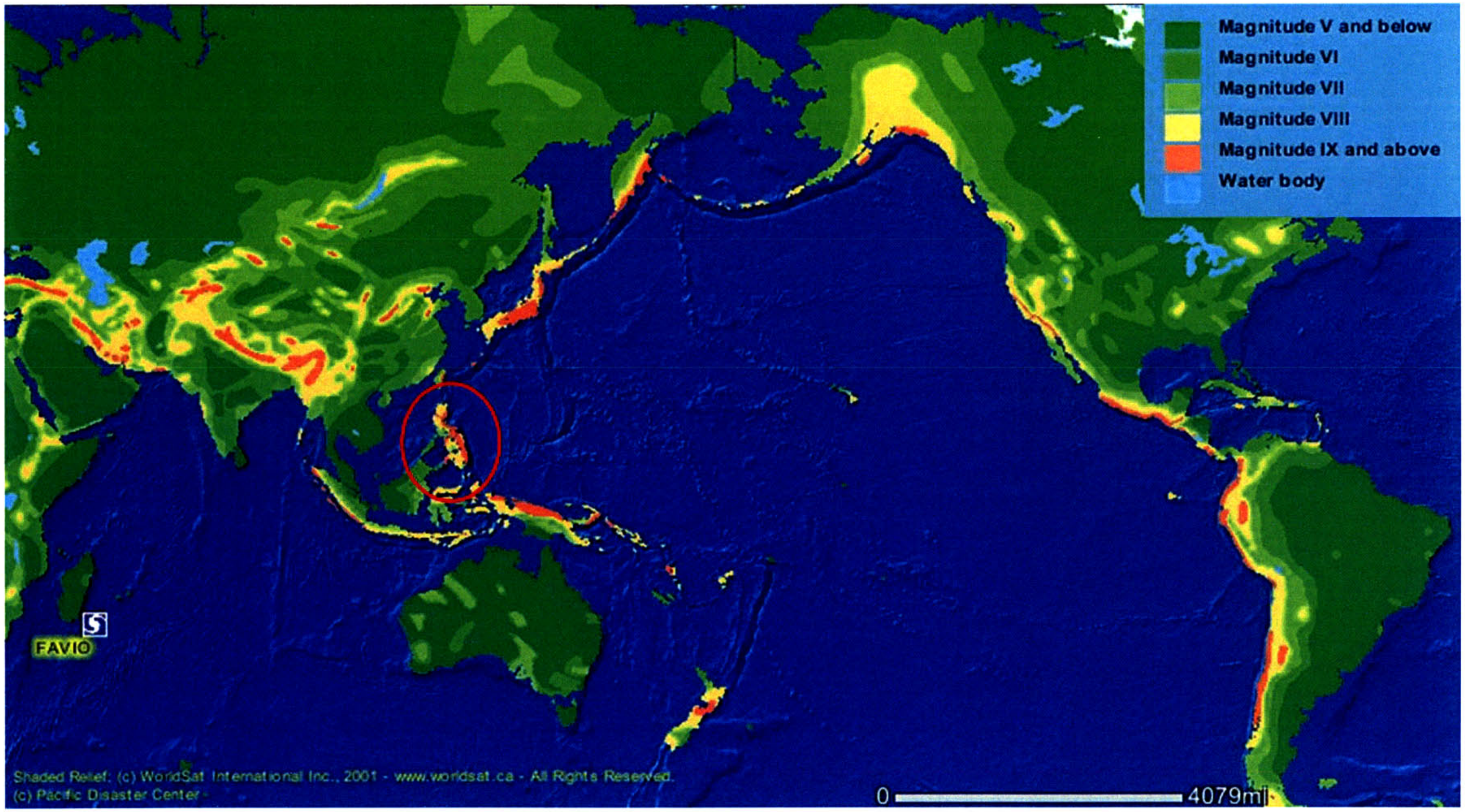

Figure 1-10 Earthquake Intensity in the Pacific[12]

[12] *Natural Hazards and Vulnerabilities Atlas* of the Pacific Disaster Center - *www.pdc.org*

1.3.3 Multi-hazard Index

The Pacific Disaster Center also elaborated a multi-hazard map for the whole Southeast Asia region, according to the possible concurrent occurrence of earthquake and tropical storms. This map clearly shows the highly sensitive position of the Philippines in the whole area, being characterized by the highest hazard indices possible – Manila lies in category 2 – high risk.

Therefore, all these data are of great importance for the issue of disaster reduction policies and the building construction industry is directly involved in this framework. Building in the Philippines means a confrontation with an extreme climate and high hazard potentials and this framework calls for an efficient and comprehensive design conceptual approach.

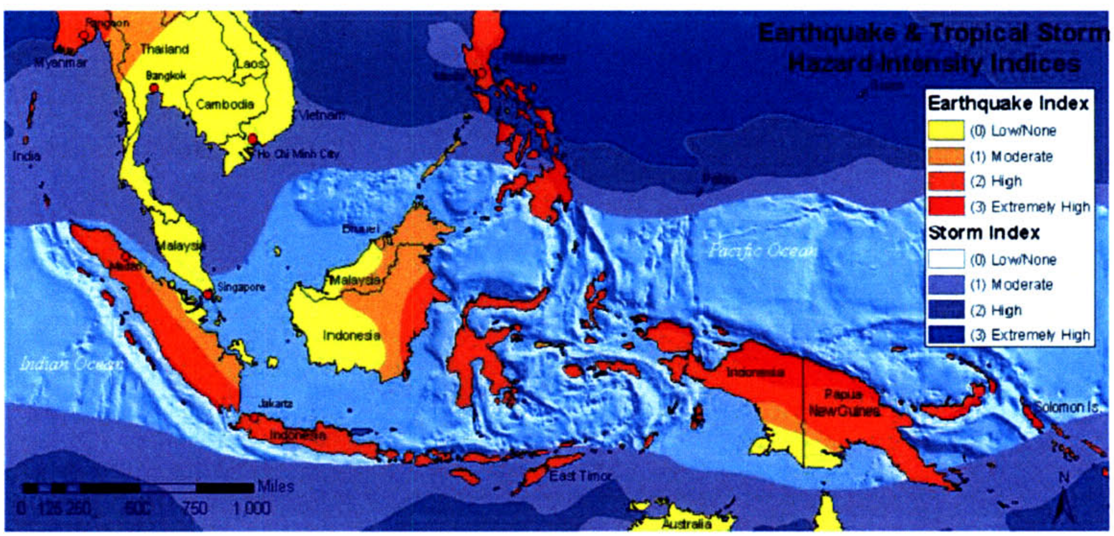

Figure 1-11 Earthquake and Storm Hazard Intensity in Southeast Asia[13]

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[13] *Natural Hazards and Vulnerabilities Atlas* of the Pacific Disaster Center - *www.pdc.org*

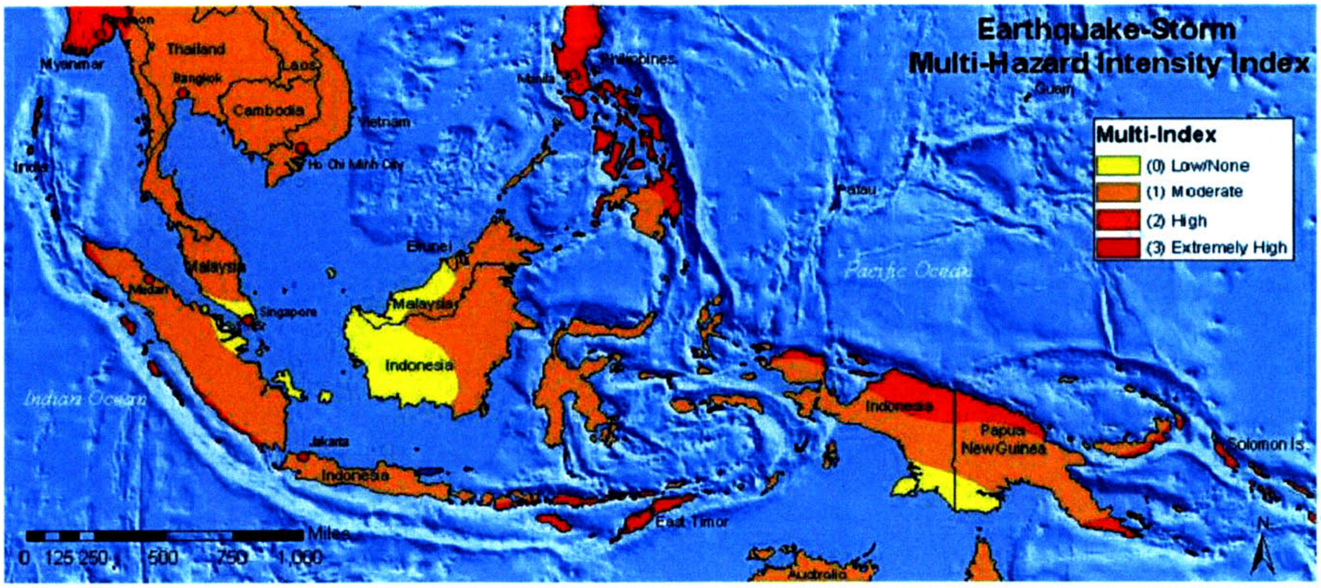


Table 2: Multi-Hazard Index for Earthquakes and Tropical Storms

		Tropical Storm Hazard			
		Low/None	*Moderate*	*High*	*Ext. High*
Earthquake Hazard	*Low/None*	Low/None	Moderate	Moderate	High
	Moderate	Moderate	Moderate	High	High
	High	Moderate	High	High	Ext. High
	Ext. High	High	High	Ext. High	Ext. High

Figure 1-12 Multi-Hazard Intensity Index in Southeast Asia[14]

ızards and Vulnerabilities Atlas of the Pacific Disaster Center - *www.pdc.org*

2 The Built Environment: Architecture in the Philippines

2.1 Architecture and extreme conditions

Building in the Philippines means a confrontation, in terms of construction and function, with extreme conditions, both climatic and structural. Designers should fight against heat, solar radiation, high levels of air humidity and rainfall and the space should be designed in order to reach comfort conditions without the use, in most cases, of mechanical cooling systems (Koenigsberger 1974). Also, all constructions should be undertaken with natural disasters in mind. Most rural housing consist of nipa[15] huts that are easily damaged but are inexpensive and easy to replace; most urban buildings are steel and concrete structures designed (not always successfully) to resist both typhoons and earthquakes. Damage is still significant, however, and many people are displaced each year by typhoons, earthquakes, and other natural disasters. In 1987 alone the Department of Social Welfare and Development helped 2.4 million victims of natural disasters. The Luzon Earthquake in 1990 caused thousands of casualties and millions of homeless.

Therefore, as well as the natural environment, even the built environment is an essential factor to be researched and analyzed for Centro Migrante project background. The principal reason lies in the importance of local historical roots: the ethnic (or vernacular) architecture in the Philippines has, through the century, developed intelligent ways of achieving indoor comfort with building forms, local materials and techniques. Although not engineered, these constructions are historical roots and links to local traditions that could be implemented to reach further innovation (quote di Alvaro Siza). Vernacular buildings all over the world are good examples of good and environmental architecture that is a response to the local natural conditions. Space efficiency, bioclimatic design and use of local and low impact materials are typical features of vernacular architectures (Lyle 1994). In the Philippines, people have mastered to have their homes shaped by the environment, by the climate, soil, vegetation, resources and natural hazard (Lim and ASEAN Committee on Culture and Information. 2001)

[15] Nipa is a special kind of native palm tree. Refer to Tagalog language terms glossary in the appendix.

An engineered and modern "vernacular architecture" approach for Centro Migrante could represent a way to achieve sustainable and economic solutions with local materials, cheap and readily available, and with a deep link to the local culture.

2.2 Vernacular constructions in the Philippines

Architecture in the Philippines today is the result of a natural growth enriched with the absorption of varied influences. It developed from the pre colonial influences of their neighboring Malay brothers, continuing on to the contemporary times. As a result, the Philippines has become an architectural melting pot uniquely Filipino with a tinge of the occidental. However, especially in suburban and rural areas, there are plenty of typical dwellings embedding the real Filipino ethnic building culture

2.2.1 Fishermen huts: the Bahay Kubo

The most typical Filipino architectural feature belongs to the Pre-Hispanic period and it represents, for centuries, the traditional dwelling of local fishermen and their families.
The bahay kubo or nipa hut is a typical traditional house found in most lowlands all over the Philippines and, despite some minor regional differences, it shows common features in its various examples (Caruncho and Mañosa 2003).
The Bahay Kubo, the ethnic response to the Filipino climate, is high pitched construction, usually open gabled to allow for ventilation, protection from the wind and rain in the typhoon season, and features wide overhanging eaves to provide shade from the hot sun.
Most of these native dwellings were often built raised (from 40 cm up to 2m) from the ground, as light structures supported by piles, in order to avoid moisture and flood danger, especially in those areas next to coastlines. The space underneath the house, called *silong*, serves as a workspace or storage space.
The structure is usually four walled with *tukod* windows, which had swinging shades that could be propped open during the day. Originally built as a one room dwelling, the nipa hut evolved as a larger family house with multiple rooms.

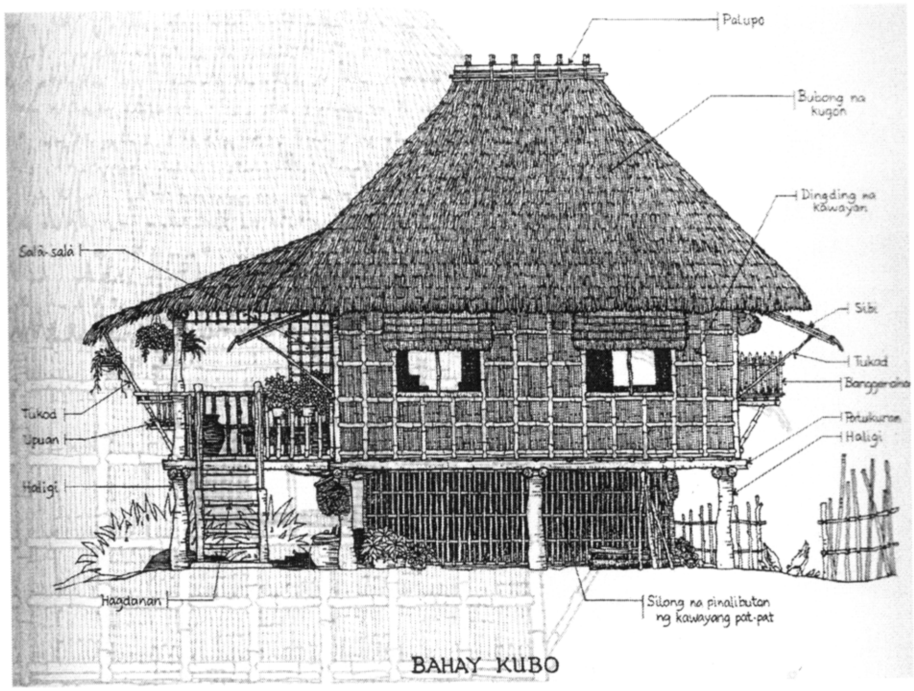


Figure 2-1 Typical Bahay Kubo

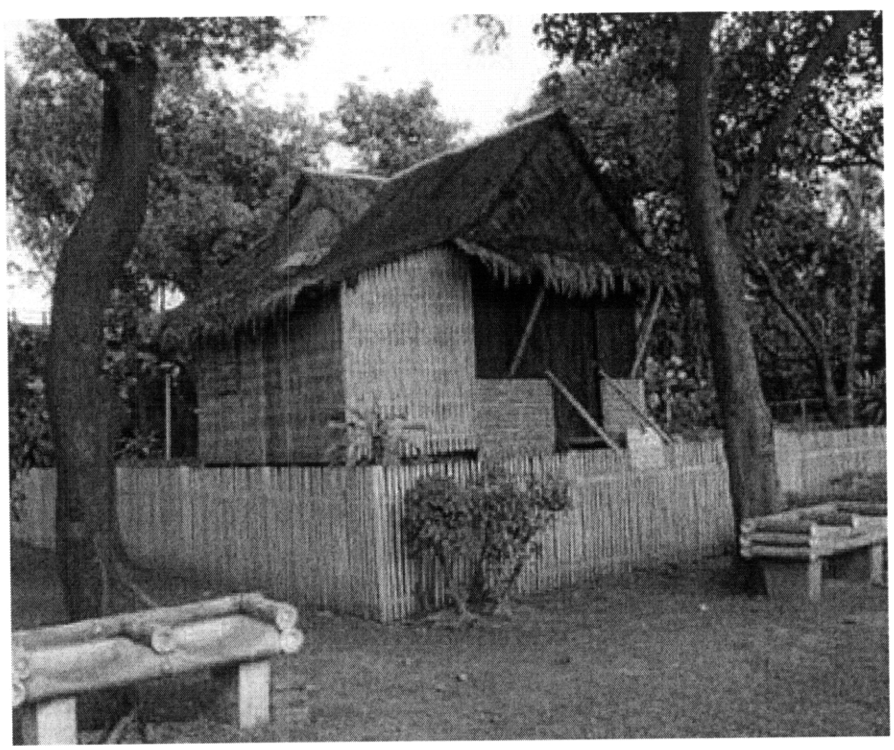


Figure 2-2 The Mabini Shrine in Manila

2.2.2 Traditional Construction Materials and Techniques

Depending on the ecology of the area, the materials may differ around the country but the major building materials are bamboo (*kawayan* in Tagalog language), rattan (*sawali*), various native woods, native palms like palma brava (*anahaw*), and nipa palms, cane, and cogon, a long grass, for thatching. Stone and clay may be used as well, but rarely. Along with nipa, bamboo has always been the most widely used material for house construction in the Philippines, for its availability and flexibility (Lim and ASEAN Committee on Culture and Information. 2001).

With a bolo (a cutting tool) and the knowledge of house construction, the early Filipino could construct a hut in just a few hours. These Pre-Hispanic Filipino lowland houses had a light stucture on top, and heavier materials on the bottom.

The frame of the house was mainly made out of bamboo or local wood and was tied together with rattan or other materials. The walls were made of bamboo and nipa, dried grass, wood, or siding made from split and pounded green bamboo halves. The materials were lashed or woven to keep the interior water tight. The floor was composed of bamboo slats (*tinilad, tilad*), usually placed convex sides up, spaced apart to increase ventilation and allow dirt to fall through. The roof was made of nipa shingles or cogon thatch. Hence, these houses are characterized by their lightweight, which helped in resisting earthquakes. The light structure was also beneficial if earthquakes or typhoon toppled the house because the lightweight of the structure would leave only little injuries.

In the past and still nowadays in rural areas, the houses have been constructed by the family itself and many Filipinos are capable of building their own houses, completing them in a few days.

2.3 Safe low cost housing: Humanity Initiatives in the Philippines

Another important issue to consider within the built environment context is the development of initiatives similar to Centro Migrante.

A review of the most active and renowned initiatives are important not only to frame Centro Migrante initiative on a social point of view, but even for reviewing techniques and approaches that could be useful in the research development.

One of the most known Filipino-based initiatives is the organization called Gawad Kalinga (GK), whose name, translated in English, means "to give care". GK started out in 1995 as a catholic-related movement to help rehabilitation of young people in the big squatter village of Bagong Silang in Caloocan City. In a little more than 10 years, GW became a nation-wide movement, focused not only on providing safe economic shelters to homeless people, but also to build up a sense of community, in order to fight the increasing poverty of the country and decrease the number of squatter areas.

Gawad Kalinga promoted the construction of roughly 900 communities and provided homeless people with self-build decent homes and with the resources to become self-sufficient. Its mottos, "Land for the landless, Home for the homeless, Food for the hungry" and "No more slums, no more violence, no more poverty" have spread over the country borders and the organization has now partners all over Asia and even America and communities build in other developing countries.

Figure 2-3 Gawad Kalinga Communities[16]

[16] www.gawadkalinga.org

2.4 The Project Location:

2.4.1 Metro Manila

Metropolitan Manila (*Kalakhang Maynila* in the local Tagalog language) or the National Capital Region (NCR) is the greater metropolitan area of the city of Manila, the national capital and largest city in the Philippines.

The global population counts 11,289,368 permanent residents, while during the day the population may exceed 16 millions[17]. These values make Metro Manila the nineteenth most populous metropolitan area in the world.

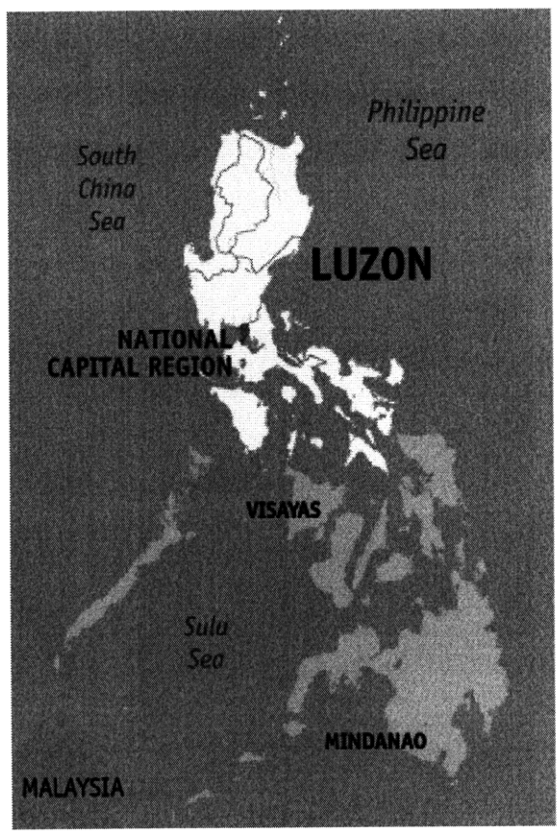


Figure 2-4 Location of Metro Manila[18]

Metro Manila is the general term for the metropolitan area that contains the city of Manila, as well as fifteen surrounding cities including Quezon City (capital from 1948 to

[17] Information available from www.wikipedia.com
[18] Image available from www.wikipedia.com

1976) and other municipalities. Manila is the political, economic, social, and cultural center of the Philippines, and is one of the more modern metropolises in Southeast Asia. Theoretically, it is the designated capital and home of the Philippine government, but, in reality, the seats of government are all around Metro Manila. The executive and administrative seat of government is located in Manila, so is the judiciary. The upper house of the legislature (Senate of the Philippines) is located in Pasay City, and the lower house (House of Representatives of the Philippines) in Quezon City.

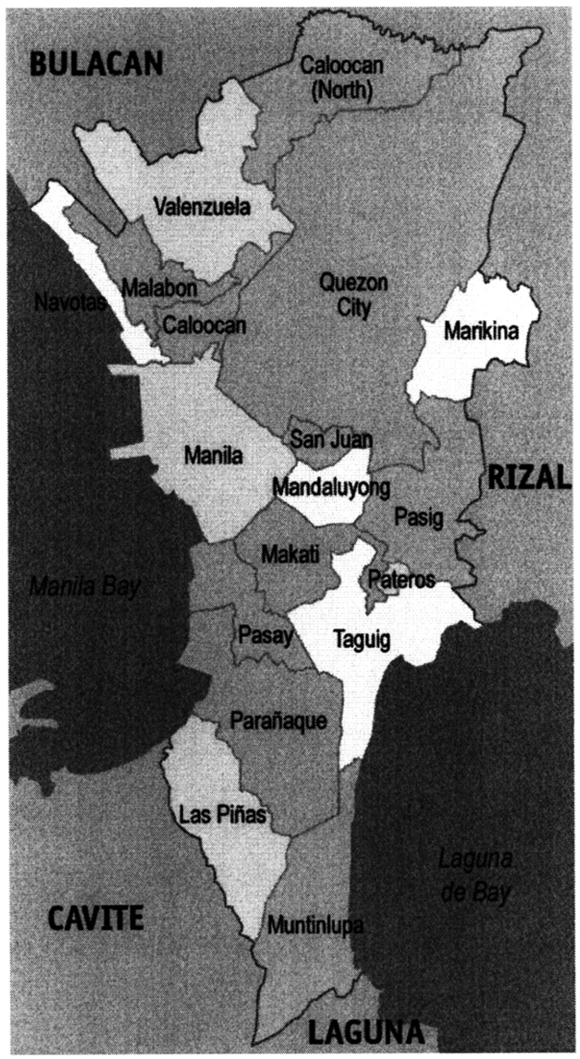


Figure 2-5 Map of Metro Manila[19]

[19] Image available from www.wikipedia.com

From a geographical perspective, the Metro Manila region is built on an isthmus with Manila Bay to the west and Laguna De Bay to the south-east and The Pasig River runs through the city and divides it in two parts.

The city of Manila lies at the mouth of the Pasig River on the eastern shores of Manila Bay, which is on the western side of Luzon. It lies about 950 km southeast of Hong Kong and 2,400 km northeast of Singapore. The river bisects the city in the middle. In addition, almost all the city sits on top of centuries of prehistoric alluvial deposits built by the waters of the Pasig River and on some land reclaimed from Manila Bay.

2.4.2 The Site: Intramuros in Metro Manila

Intramuros or the walled city of Manila is a central neighborhood located on the southern side of the Pasig River, close to the rivers entrance into Manila Bay[20]. Intramuros was the original urban core of Manila, being the old Spanish neighborhood, one of the most ancient areas of the city, built by the Spaniard when they took possession of the Philippines country in the XVI century.

Figure 2-6 Entrance of Intramuros

[20] www.philippines-travel-guide.com/intramuros.html

Its name, taken from the Latin, *intra muros*, "Within the walls", was referring to the wall enclosure of the original Spanish fortified city, described as surrounded by thick, high walls and moats. During the Spanish Period, Intramuros was considered Manila itself. The construction of the area took place since 1571, by Miguel Lopez de Legaspi, and was originally set as a military fortress, covering an area of 6 acres with 6 meters high walls. Originally, only the Spanish Elite and *Mestizos* (mixed race) were allowed to live inside Intramuros, where at night the city gates were locked down. The natives and Chinese were banned and forced to live outside the great walls, later surrounded by a moat.

Figure 2-7 Distant view of Intramuros

Throughout the years, the Spaniards set the urban layout of the area into 51 blocks and filled Intramuros with impressive buildings, hospitals, schools, administrative palaces, military barracks, 12 churches and they imported the traditional Spanish architectural language. Intramuros served as the center of political, military and religious power of the Spaniards during the time that the Philippines were a colony of Spain. After the end of the Spanish domination in 1898, Intramuros remained the historical core of Manila, although the city expanded in area and number of inhabitants. During World War II, Intramuros was used by the Japanese as their garrison and prison. It was severely damaged, along with most parts of Manila, during the Allied bombings to liberate the city from Japanese occupation. The US Administration filled the moat in to prevent the onset of disease. Currently, Intramuros is the only district of Manila where old Spanish-era influences were retained and it represents the most known tourist attraction of the city. The most notable attractions of the area are represented by buildings like the Manila Cathedral, St. Agustin Church and Museum, Fort Santiago and Rizal Shrine; all these monuments are examples of the rooted Spanish architecture in the Philippines, with its heavy stone materials and high decorative motives, which are so different from the vernacular architecture of the country and its bamboo construction tradition.

Much of the development of present-day Manila occurred outside the gates of Intramuros, leaving the old walls, streets and churches of Intramuros minimally touched by modernization. Some areas of neighborhood are not safe at nighttime and some slum constructions have occurred along the streets.

2.4.3 Seafarers lodging in Intramuros: The original project Pier One

As explained in the thesis introduction, Centro Migrante Inc. already developed an initial prototype for their business initiative, called Pier One, which opened in 2003. Pier One was originally conceived and developed by Iliac Diaz only, later joined by the other members of Centro Migrante. The housing site occupies a lot in the south area of Centro Migrante and has been successfully operating since 2003.[21]

2.4.4 Centro Migrante in Intramuros: a possible construction lot

According to Centro Migrante's business purpose, the new housing community should occupy a construction lot in South Intramuros, just opposite the existing Pier One, along Victoria St, close to the ancient Spanish walls.

The lot has been considered as a design location for the research project here presented and all its geographical, climatic and orientation features have been considered in the development of Centro Migrante design.

The site measures roughly 48m on the short side and 65m on the long side, for a total area of 3,120 m^2. Its main orientation axis lies in the North-East – South-West direction and this is an important parameter to take into account, due to solar and wind orientation

[21] See Introduction

of the new project. Currently, the lot is occupied by several unidentified slum constructions and it is bordered by a tall historical building, which blocks the whole south side view of the lot

Figure 2-8 Google Earth aerial view of South Intramuros

Figure 2-9 View of Intramuros with possible site

PART TWO:

PROJECT CONCEPTUALIZATION

CHAPTER 3

3 Centro Migrante: Design Concepts and Requirements

3.1 The Conceptual Design Framework: a Methodology

3.1.1 Development of a Systemic Design Methodology

The research aims to propose the most appropriate and suitable configuration to the Centro Migrante business initiative, focusing on a global methodology based on a systemic thinking[22] approach. Many factors have been considered in the design development and, rather than a sum of requirements, the final outcome is meant to be an integration among the several and different aspects and constraints of the whole project. The project for Centro Migrante is a specific design response, tailored to precise and detailed conditions, climate and location, but it also embeds a systemic methodology to address the problem of designing low cost sustainable housing for developing countries in a broader and holistic sense. In this perspective, the methodology applied demonstrates a consistent design approach and framework that could be replicated in different situations. Also, this feature is in line with the goal of the Centro Migrante group, to extend their business philosophy to other situations according to the needs. In the spirit of the group, Centro Migrante's idea and realization will offer a response to an affordable housing need and it will represent an important prototype that could be expanded in further directions for seafaring populations in other countries and for migrant populations of other professions. The design methodology here developed fits perfectly within this framework.

3.1.2 The Concept of Sustainability and Building Performance

In ancient times, Vitruvius had stated that primary requirements of an efficient building were embedded in the triad *Firmitas*, *Utilitas* and *Venustas,* Firmness, Function and Beauty, (Vitruvius, Rowland et al. 2002) which represented the fusion of structural, functional and aesthetic requirements. In modern times, the original triad is always

[22] Systemic or systems thinking here is intended as an approach to integration based on the linkages and interactions between the elements that comprise the entirety of the system. In a philosophical perspective, this approach is a result of the General Systems Theory introduced by Ludwig Von Bertalanffy in 1960s.

truthful but has been implemented by the further dimension of *Performance*, mainly intended as the building global behavior, in response to its natural environment. The issues of sustainability and sustainable design are indeed deeply rooted in the meaning of Building Performance, as they refer to a building behavior sensitive to its environment. Sustainability has become the great research theme in the *no-man-land* between and architecture and engineering and, recently, new design methods, materials and construction techniques have been devised to improve the functionality and safety of buildings towards both ordinary and exceptional environment interaction (Lyle 1994), (Stein 2006), (Jones and Hudson 1998).

In the Author's opinion, the main issue beyond the concept of sustainable design is the integration of all design aspects and requirements. Sustainable design brings together architecture, structural and mechanical engineering, urban planning and environmental engineering, in order to create a comprehensive sphere of action, whose common denominator is shaping the building according to the environmental conditions (climate and natural hazards). In this thesis, the main research goal has been to accomplish the goal of sustainability for the housing units and, hence, a framework for sustainable design in developing countries has been elaborated.

3.1.3 Sustainable Integrated Design in Developing Countries

Currently, the concept of performance in building design is addressed in multifold perspectives, especially within the so-called high-tech architectural trends. However, it is important to point out that the high-performance feature does not belong only to this kind of constructions, but it is relevant to several and different building environments and contexts, even when high-tech solutions are not feasible.

Some recent studies (Gutierrez 2000), (Gutierrez 2004) pointed out how the performance is particularly important when dealing with planning and construction in developing countries, where appropriate technology and low-tech solutions should be sought and implemented, with the purpose of obtaining efficient design to improve the living conditions of people.

The key-issue is to perform a "passive approach", meaning that the performances of buildings are not derived by strengthening their elements or inserting special apparatuses but by a suitable use of structural configurations and natural characteristics of the construction materials. Within this research work, the concept of sustainable design in developing countries has been carried out according to three main key concepts:

Study of local climate

Study of locally available materials and techniques (vernacular architecture)

Development of appropriate technology

3.1.3.1 Study of local Climate

The control of the internal environment and the achievement of comfort conditions can be obtained only if the external conditions are fully known and assessed. In this perspective, a climate responsive design approach has been followed. (Givoni 1998), (Gut, Ackerknecht et al. 1993), (Hyde 2000).

3.1.3.2 Study of locally available materials and techniques (vernacular architecture)

"Vernacular constructions represent a very large share of the built environment. Being, by definition, non-engineered constructions, they are the result of ancient traditions, improved with time as a response to the requirements of their social and physical environment. Consequently, they are well-fitted solutions to the demands of their social and natural environment and possess a certain built-in fixity, only modified as a result of persistent and extraordinary circumstances" (Gutierrez 2004). This definition summarizes the importance of local cultural factors and the concept of innovation through tradition. By proposing engineered solutions which are inspired from vernacular constructions and are linked to traditions, it is possible to achieve sustainable designs.

3.1.3.3 Development of appropriate technology

The issue of "appropriate technology" (Stulz and Mukerji 1988) is deeply linked with the previous two key issues and it involves the development of economic, low-tech, tailored on the available materials, conditions and target people. Practically speaking, appropriate technology is the step that allows to join climatic studies results with vernacular and technical aspects, in order to produce a relevant and feasible design solution.

3.1.4 Integrated Design for Centro Migrante

Within this framework, the planning process of Centro Migrante, the core of this research work, has been structured in order to put forward a model of sustainable community, planned according to the abovementioned integrated design criteria. Indeed, the concept of "integrated design" is the basic idea behind the whole process and it fully embeds the systemic strategy for interlacing architectural, functional, structural and sustainability requirements and solutions into a single multifaceted approach. Therefore, starting in the early design stages, issues regarding space layout and functions, structural loads and climatic comfort requirements have been deeply analyzed in order to establish a correct solving strategy and a comprehensive global solutions.

In this chapter, our goals are to:

Outline the criteria that can lead the architectural conception to achieve a suitable and sustainable building behavior in a developing country context like Manila

Enlighten and thoroughly assess the main project requirements meeting the client criteria and the optimal performance criteria

More precisely, the detailed Sustainable Integrated Design proposed for Centro Migrante is structured into the following intertwined phases:

- Architectural Requirements: client needs and efficient layout issues
- Structural Requirements: Optimization of structural frame in relation to loads and issues of "collaborative" structural design.
- Internal Comfort Requirements: detailed climatic data analysis to obtain a "project shaped by its own environment" and a Climate Responsive design (Gut, Ackerknecht et al. 1993), (Hyde 2000).

3.2 Architectural Requirements

In regard to the architectural issues, most of the preliminary conditions have been already set by Centro Migrante business plan. The Company produced a detailed Design and Development program that fully explains the main requirements for the housing project.

According to this document, main conceptual requirements to fulfill are the following:

- modular design
- economic and cost-effective
- easy assembly and disassembly

The company aims to replicate and improve the existing prototype Pier One with a more sustainable and efficient construction, follow the same administration system and introduce a new self-help policy.

Centro Migrante community is planned to lie on two lots of roughly 3,000 square meters, one for single units, one for family units. Each site will be enclosed by walls and a proper biometrics system will grant access to the tenants. The rule of self help community and self build homes will apply for both Single and Family Units. This research work is focused on proposing a detailed design for the Single Units lot, although the same methodology and modules can be applied to the Family Units lot.

3.2.1 Summary of Requirements set by Centro Migrante Inc.

- 3,000 square meters site in Intramuros, Metro Manila area
- Life expectancy of 20 years (duration of lease) with possible disassembly-reassembly every 5 years
- 30% of site area should be occupied by administration building and commercial spaces
- Single Units and Family Units should occupy two different slots
- Housing design should improve sense of community and concept of self-build, self-maintained homes.
- Each Single Occupancy Unit (SOU) should measure 2x3 meters, following the minimum single use space requirement of the Philippine Building Code
- Maximum cost for each SOU should be 300 US dollars

3.2.2 Modular Design

Following the self help model, the housing units will be erected by the seafarers-tenants. This issue calls for a simple design and the construction systems ought to be easy and straightforward to mount. The units should be made out of prefabricated modular elements, with the possibility of a further expansion from one to two stories. According to Centro Migrante's needs, the whole system should feature flexibility and expandability.

3.2.3 Design for Disassembly

One of the key-feature of the new Centro Migrante will be the possibility of dismantling the units and remounting them in another location. This feature is motivated mainly by land and leasing issues in Manila, where landowners are entitled to break the lease anytime, with short notice. Each housing unit should be deconstructable at any given point in its lifetime and should be made out of component especially designed for re-use, both structural and non-structural components. The framework of Design for Disassembly varies specifically from building to building and it is tailored to the specific conditions of the site and the location. However, according to several literature sources (Yeang 2006), (Crowther 2005), (Crowther 2001)there are some basic design principles to follow:

Design for versatility

Every element, component or system should be designed in order to incorporate different uses with minimal changes.

Design for durability (life time)

Elements should fulfill their function all through their expected lifetime.

Design for ease of change/access

In order to facilitate changes and deployment, elements should be easily accessed with minimal damages to adjacent assemblies. Also, elements with expected shorter lifetime should be more accessible than ones with longer life expectancy. This will reduce unnecessary waste.

Simplicity of design

Simple geometric rules reduce (apparent) complexity and give logic to the whole project

Independence of materials assembly

Minimize interconnectivity and dependence of elements assembly

Element labeling and information

Avoid finishing of materials, like plaster or special paintings. Use materials with inherent finishing.

Expose connections

Bolted, lashed connections should be preferred and exposed in order to facilitate the disassembly. Glued and welded connections should be avoided.

The architectural design should follow these essential guidelines in order to develop reusable materials, joined with fast and simple connections.

3.3 Structural Requirements

As discussed in the first chapter, the Philippines are one of the most disaster-prone areas in the world and this issue plays a key-role for the choice of an appropriate structural system and design philosophy, namely design for lateral loads. Main sources of lateral loads are earthquakes and strong winds and, although they both require a well-designed Lateral Forces Resisting System (LFRS), they have slightly different specific requirements for a stable system. The key issue to establish design parameters for the LFRS consists in a complete assessment of potential loads and their risk. A detailed load analysis will be presented for both seismic and wind loads in the next chapter. As for general design principles, several literature sources, (Ambrose and Vergun 1987), (Ambrose and Vergun 1999), (Connor 2003), have been consulted to establish a project design philosophy.

3.3.1 Seismic Load – Principle of earthquake resistance architecture

An adequate earthquake resistant construction should be able to withstand the extreme events of ground shaking and other earthquake related effects likely to occur during its lifetime, fulfilling previously defined performance objectives defined in terms of prescribed limits of tolerance. Broadly defined, these objectives are life protection for the building occupants and minimization of property damage. Attributes of a good seismic design are listed below:

- Regularity in Plan and Height
- Ductile structural behavior
- Avoidance of foundations differential settlements
- Relatively flexibility of connections
- Lightweight construction
- Use of shear wall and/or bracings
- Use of rigid diaphragms for floors and ceilings

A full treatment of seismic design criteria has been carried out in chapter 4, with the aid of structural building code.

3.3.2 Typhoon Load – Problems of wind excitations

The main problems derived from typhoons are the sustained storm wind conditions which can last even for days, with speed up to 210 km/h in the Manila area. The effects on wind on low rise buildings are summarized in the next figure.

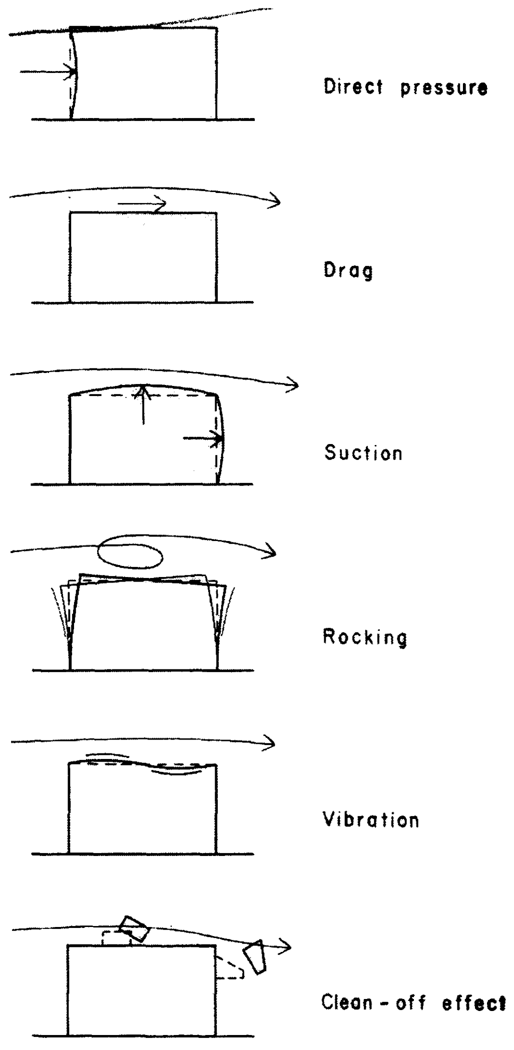


Figure 3-1 Wind Effects on Structures

Direct Positive Pressure

Surfaces facing the wind and perpendicular to its blowing direction (windward side) receive a direct impact effect from the wind (Ambrose and Vergun 1987). The higher the wind speed, the larger the pressure effect on the building side since it is function of the wind speed to the second power.

Aerodynamic Drag

The drag effect is mainly due to the fact that wind does not stop when hitting an object, but, being a fluid, it flows around it, causing drag effects on the surfaces that are parallel to wind direction.

Negative Pressure

On the leeward side of the building or of the roof a suction effect usually occurs, consisting of pressure outward on the surface. By comparison with the pressure on the windward side, this effect is called negative pressure. (Ambrose and Vergun 1987). Proper stiffening elements should be provided to withstand both pressure effects and ensure all surfaces from aerodynamic drags.

In order to withstand wind loads, a full assessment of the load entity has been performed in the following chapter with the aid of structural building code and full data about maximum wind speed in Manila area. With these data, it is possible to conceive and design the proper structural elements to increase the stiffness of the building surfaces.

3.4 Internal Comfort Requirements

3.4.1 Climate Responsive Design

In extreme climates, the natural environment should be the main determinant of the building form and layout, in order to create internal comfort conditions. A Climate Responsive Design approach should be carried out, starting from a detailed analysis of temperatures and climatology statistics. The most comprehensive and complete definition of Climate Responsive Design has been elaborated by the Energy Design Resource center, a research organization based in California.

"Climate-responsive design is a strategy that seeks to take advantage of the positive climate attributes of a particular location, while minimizing the effects of attributes that may impair comfort or increase energy requirements. Designers who strive to develop comfortable, low-energy buildings can enjoy the benefits of climate-responsive design by considering five basic points in the course of designing new commercial buildings.

- Understand climate zones and microclimates.
- Understand the basic physiology of human thermal comfort.
- Control the sun to reduce loads and enhance visual comfort.
- Use thermal mass to improve comfort and efficiency.
- Select space-conditioning strategies that are climate responsive" [23]

The major feature of the Manila tropical climate is the hot, humid condition and the constant presence of dampness. The air temperature remains constantly high, with almost no thermal variation between day and night. Generally speaking, air movement and circulation is the key fact to achieve indoor comfort, in absence of mechanical equipment to cool down the air. Natural ventilation through cross circulation and multiple openings is crucial to achieve the required movement for passive cooling. (Koch-Nielsen 2002), (Givoni 1998), (Gut, Ackerknecht et al. 1993).

In establishing a precise series of requirements based on climate data, the Tables developed by Carl Mahoney[24] were the tool used for microclimate site analysis, in order to provide an initial conceptual design framework for designing in subtropical climates. The Mahoney tables provide great utility in establishing guidelines suitable to achieve indoor comfort in those extreme weather conditions (Heerwagen 2003).

[23] http://www.energydesignresources.com/resource/27/

[24] Carl Mahoney is an international expert in the area of Passive and Low Energy Architecture (PLEA) and is well known for his work on the Mahoney Tables for the United Nations in 1980s, pioneering work on the effects of combining thermal mass and insulation in building elements and the design of finite difference thermal simulation models for buildings. The Tables are now used in tertiary programs in countries throughout the world.

3.4.2 Mahoney Tables

When the climatic pattern emerging from the data clearly corresponds to warm humid or hot dry types, it is simple to reach suitable performance specifications, whereas in composite climates, the seasonal requirements may be contradictory. For simple passive buildings, not assisted by mechanical means of heating or cooling, Mahoney worked out a weighing system to assess the relative importance of conflicting requirements. The system takes into account the duration and severity of the various climatic factors. The Mahoney tables classify precisely the nocturnal and diurnal thermal stress in centigrade scale of temperature. The procedure consists in compiling a series of tables containing climatic data statistics:

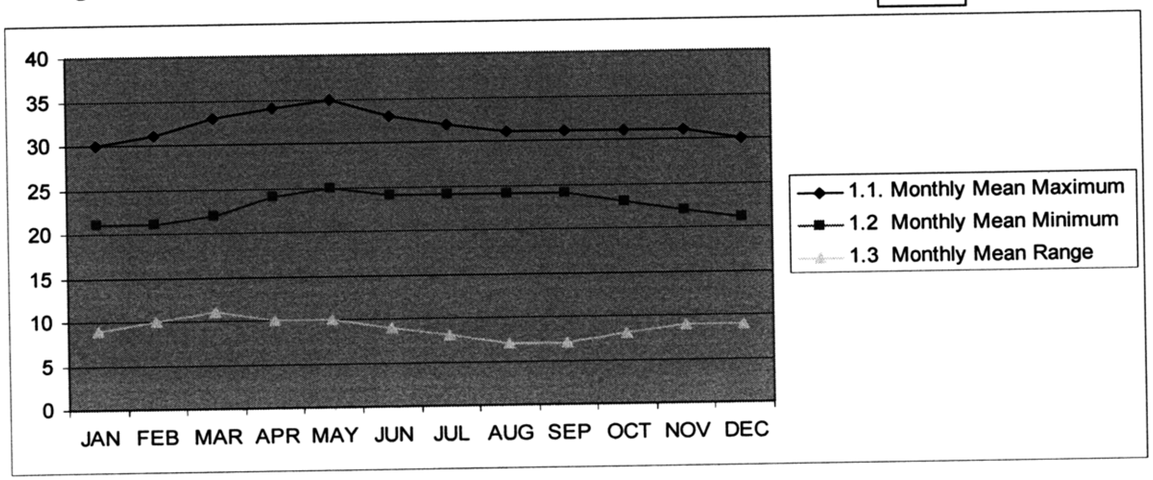
- Monthly Temperatures
- Relative Humidity and Precipitations
- Thermal Stress and Comfort Conditions

These data are then used to compile a fourth table on climatic stress, which gives the Mahoney Indicators; the Indicators provide the final step to obtain design recommendations and details for climate responsive design.

Table 3-1 Monthly Temperatures[25]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1.1. Monthly Mean Maximum	30	31	33	34	35	33	32	31	31	31	31	30
1.2 Monthly Mean Minimum	21	21	22	24	25	24	24	24	24	23	22	21
1.3 Monthly Mean Range	9	10	11	10	10	9	8	7	7	8	9	9

		=	
	Maximum Monthly Mean Maximum	=	35
	Minimum Monthly Mean Minimum	=	21
Annual Mean Temperature	**AMT = (Max Mo Me Max +Min Mo Me Min)/2**	=	28
Annual Mean Range	**AMR = (Max Mo Me Max - Min Mo Me Min)**	=	14



[25] All the data in the tables come from the PAGASA Institute, www.pagasa.dost.gov

Table 3-2 Relative Humidity and Precipitations

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2.1. Av. Monthly Relative Humidity (%)	75	61	68	65	71	79	83	84	85	84	80	78
2.2 Humidity Group	4	3	3	3	4	4	4	4	4	4	4	4
2.3 Monthly Precipitation (mm)	19	8	11	21	165	265	420	486	330	271	129	75
2.4 Prevailing Wind Direction	NE	NE	NE	NE	NE	SW	SW	SW	SW	NE	NE	NE
2.5 Secondary Wind Direction	varies	varies	varies	varies	varies	varies	varies	varies	varies	varies	varies	varies

Annual Precipitation = 2200

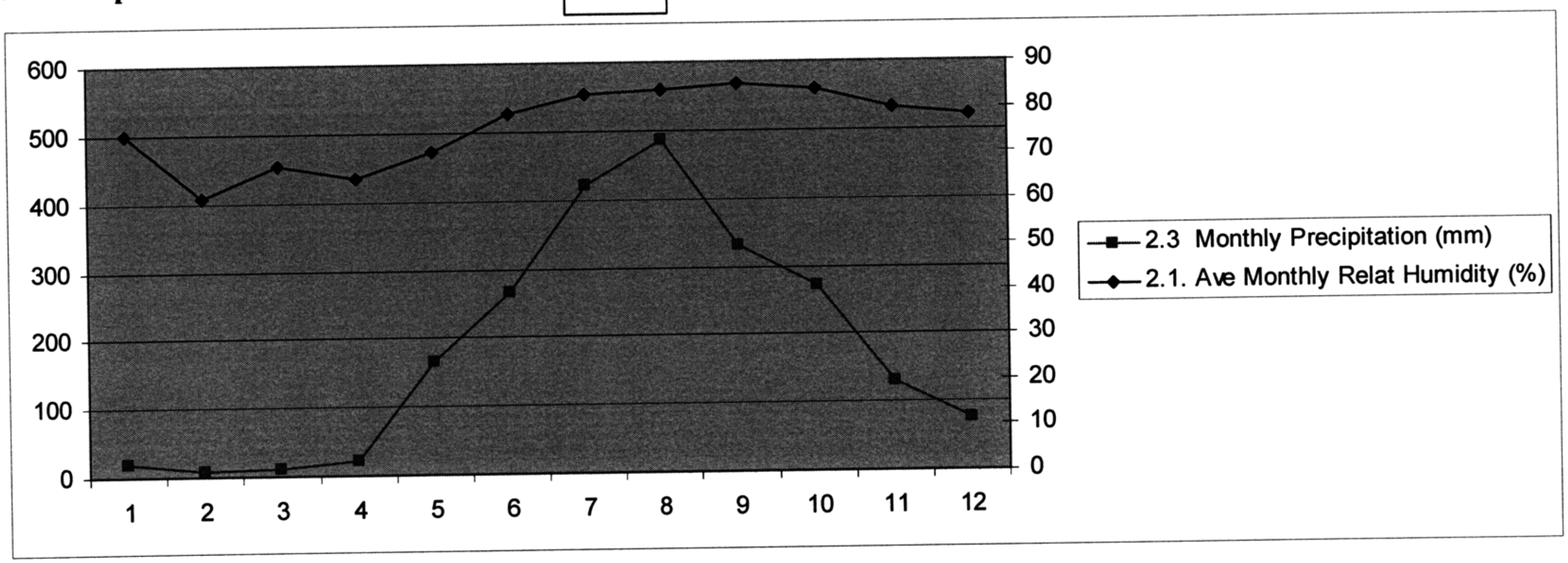


Table 3-3 Thermal Stress and Comfort Conditions

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
3.1 Humidity Group	4	3	3	3	4	4	4	4	4	4	4	4
3.2 Monthly Mean Maximum (deg C)	**30**	**31**	**33**	**34**	**35**	**33**	**32**	**31**	**31**	**31**	**31**	**30**
3.3 Day Comfort Temp Max	21	24	24	24	21	21	21	21	21	21	21	21
3.4 Day Comfort Temp Min	17	17	17	17	17	17	17	17	17	17	17	17
3.5 Monthly Mean Minimum	**21**	**21**	**22**	**24**	**25**	**24**	**24**	**24**	**24**	**23**	**22**	**21**
3.6 Night Comfort Temp Max	27	29	29	29	27	27	27	27	27	27	27	27
3.7 Night Comfort Temp Min	22	23	23	23	22	22	22	22	22	22	22	22
3.8 Thermal Stress Day	H	H	H	H	H	H	H	H	H	H	H	H
3.9 Thermal Stress Night	C	C	C	N	N	N	N	N	N	N	N	C

H = Hot

C = Cold

N = Neutral

Table 3-4 The Six Indicators (from Thermal Stress, Humidity and Rainfall)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
FOR HUMID CONDITIONS													
H.1 Air Movement Essential	1				1	1	1	1	1	1	1	1	**9**
H.2 Air Movement Desiderable													**0**
H.3 Rain Protection Needed						1	1	1	1	1			**5**
FOR ARID CONDITIONS													
A.1 Thermal Storage Needed			1										**1**
A.2 Outdoor Sleeping Useful													**0**
A.3 Cold-Season Problems													**0**

The Mahoney Indicators are then used to assess the climatic requirements with the final evaluation charts, that associate particular design conditions to the Mahoney numerical indicators[26].

[26] The tables have been taken from Heerwagen, D. (2003). Passive and Active Environmental Controls: Informing the Schematic Designing of Buildings, McGraw-Hill Science/Engineering/Math.

Table 3-5 Recommended Specifications

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
9	0	5	1	0	0

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
								Layout
			0–10			✓	1	Orientation north and south (long axis east–west)
			11, 12		5–12		1	Orientation north and south (long axis east–west)
			11, 12		0–4		2	Compact courtyard planning
								Spacing
11, 12							3	Open spacing for breeze penetration
2–10						✓	4	As 3, but protection from hot and cold wind
0, 1							5	Compact lay-out of estates
								Air movement
3–12						✓	6	Rooms single banked, permanent provision for air movement
1, 2			0–5			✓	6	Rooms single banked, permanent provision for air movement
1, 2			6–12				7	Double banked rooms, temporary provision for air movement
0	2–12						7	Double banked rooms, temporary provision for air movement
0	0, 1						8	No air movement requirement
								Openings
			0, 1		0	✓	9	Large openings, 40–80%
			11, 12		0, 1		10	Very small openings, 10–20%
Any other conditions							11	Medium openings, 20–40%
								Walls
			0–2			✓	12	Light walls, short time-lag
			3–12				13	Heavy external and internal walls
								Roofs
			0–5			✓	14	Light, insulated roofs
			6–12				15	Heavy roofs, over 8 h time-lag
								Out-door sleeping
				2–12			16	Space for out-door sleeping required
								Rain protection
		3–12				✓	17	Protection from heavy rain necessary

Table 3-6 Detail Recommendations

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
9	0	5	1	0	0

Detail recommendations

Size of opening

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
			0, 1		0	✓	1	Large: 40–80%
			0, 1		1–12		2	Medium: 25–40%
			2–5				2	Medium: 25–40%
			6–10				3	Small: 15–25%
			11, 12		0–3		4	Very small: 10–20%
			11, 12		4–12		5	Medium: 25–40%

Position of openings

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
3–12						✓	6	In north and south walls at body height on windward side
1–2			0–5			✓	6	In north and south walls at body height on windward side
1–2			6–12				7	As above, openings also in internal walls
0	2–12						7	As above, openings also in internal walls

Protection of openings

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
					0–2	✓	8	Exclude direct sunlight
		2–12				✓	9	Provide protection from rain

Walls and floors

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
			0–2			✓	10	Light, low thermal capacity
			3–12				11	Heavy, over 8 h time-lag

Roofs

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
10–12			0–2			✓	12	Light, reflective surface, cavity
10–12			3–12				13	Light, well insulated
0·9			0–5				13	Light, well insulated
0·9			6–12				14	Heavy, over 8 h time-lag

External features

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
				1–12			15	Space for out-door sleeping
		1–12				✓	16	Adequate rainwater drainage

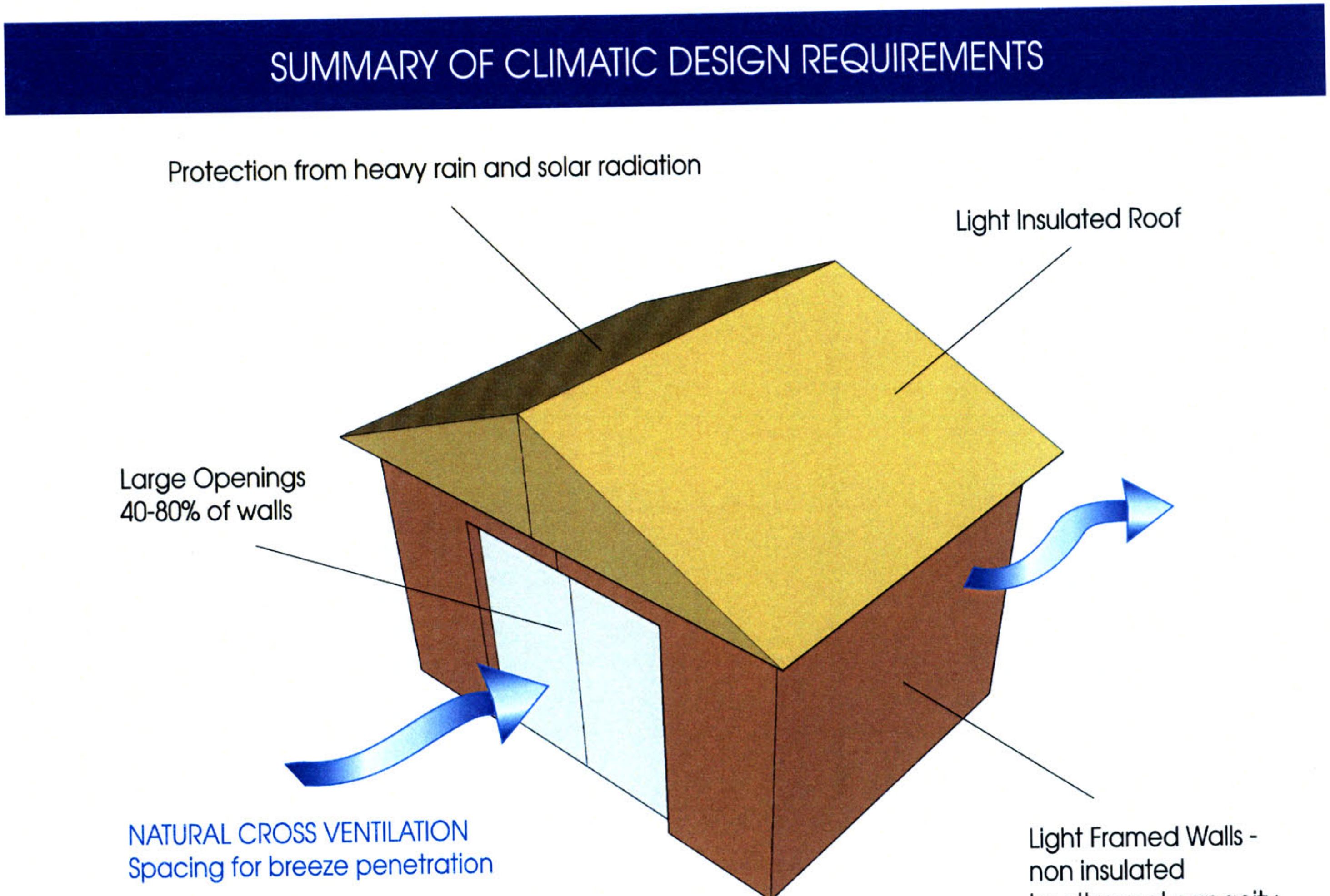


Figure 3-2 Summary of Mahoney Tables outcome

The Mahoney Tables were helpful to establish a series of preliminary requirements and bioclimatic principles for designing in warm humid climates.
In addition, other literature sources (Hyde 2000), (Koch-Nielsen 2002), (Gut, Ackerknecht et al. 1993) provide further design guidelines for these special climatic areas. The essential facts are summarized below:

- provide maximum ventilation and free air circulation by large openings
- provide maximum shading of direct and indirect solar radiation
- avoid heat storage
- use ventilated double roofs
- use reflective outer surfaces
- use vegetation to moderate solar impact

The main design requirement is an efficient ventilation system, which maximizes the indoor-outdoor air circulation through multiple openings and proper wind orientation. Cross ventilation schemes and devices to increase air movement are key issues to achieve passive cooling. Therefore, wind orientation, along the direction of the prevailing breezes, is highly important, more than solar orientation (Koch-Nielsen 2002). However, the solar radiation is intense and diffuse due to haze and, therefore large shading devices are needed to lower the induced solar heating; the east-west orientation should be minimized as to avoid the sun penetrating into the inner spaces, due to the low beams inclination in the morning and late afternoon.
Also, due to the minimum temperature difference between day and night and the impossibility to perform nighttime cooling, the principle of heat storage and thermal mass properties of materials is not applicable for this climate areas and should be generally avoided. On a general perspective, materials with heat absorption and storage properties should be avoided. Materials with low thermal mass, high reflective or light surfaces and double skin structures are thus the most suitable choice.

For vertical walls, insulation is not required if they are shaded, (Koenigsberger 1974), (Gut, Ackerknecht et al. 1993). Also, light colored materials would be help not to attract solar radiation.

Vegetation is rich and flourish in those areas and can play a main role in improving the climatic conditions. It provides efficient shading to building and people but needs to be placed accordingly, in order not to prevent air circulation and natural ventilation.

Regarding the urban layout, the need for maximum air movement should call for a open and scattered settlement pattern (Givoni 1998), with plenty of vegetation and shaded or canopied footpaths. This issue should be compromised with the scarcity of land in downtown Manila and, hence, a proper balance should be achieved.

3.5 *Putting All Together: Integrated Design Requirements*

In the previous sections, the global architectural, structural and sustainability requirements have been assessed separately and independently from one another, in order to establish the proper design conditions for the housing units.

At this point of the conceptual design, the following step is putting all together, namely reaching a global design perspective, which could take into account all the requirements within a single framework. This basically means performing an integrated design action.

The complete objective is reached with an appropriate technology, which will take into account the availability of local materials as further design parameter.

CHAPTER IV

4 Building Code Requirements

Three codes have been consulted: the International Building Code 2003 (IBC 2003), the National Building Code of the Philippines (NBC) and the Philippines National Structural Code (NSC). While the IBC have been consulted for more general issues and for comparison, the Philippines codes have been used extensively in order to have full compliance with the local regulations.

4.1 Architectural issues

The National Building Code of the Philippines, (NBC), (1972) summarizes a series of requirements concerning room and building elements dimension, as well as general regulations concerning site design and fire protection. The table below summarizes the main issues concerning the design of Centro Migrante.

Description	Minimum Requirement	Section
Floor to Ceiling height	2.40 m	3.01.08 b1 b2
Surface Area of room	6 m^2	3.01.08 b1 b2
Window Surface	1/10 of room area	3.01.08 b1 b2
Air Volume per room per person	14 m^3	
Design Live Load	150 kg/m^2 (30 psf)	
Design Dead Load	66 kg/ m^2 (13 psf)	
Wind Load	150 kg/ m^2 (30 psf)	

The last three requirements listed, concerning the design loads, are the minimum loads to be considered.

4.2 Structural issues

The total lateral load affecting Centro Migrante design is a combination of wind and seismic excitations and their estimation has been carried out with the aid of the building codes.

4.2.1 Seismic Loads

In addition to wind loads, earthquakes are the other source of dangerous lateral loads for Centro Migrante. Given the particular condition of the site and the global disaster-prone features of the whole country, the estimation of earthquake design loads, in terms of Peak Ground Acceleration (PGA) had a high importance in the whole project development.
Proper seismic design parameters have been obtained by following a combination of probabilistic and deterministic methodology, organized in the following steps:

Establishment of proper and acceptable level of risk
Review of the historical seismicity of the Manila region in order to attain statistical data references
Based on the project life expectancy and the acceptable level of risk, evaluation of the earthquake return period and corresponding magnitude.
Calculate PGA with proper attenuation relationship and estimated relevant site-to-source distance

This approach has been used to obtain the proper Peak Ground Acceleration for Centro Migrante design, which equals to 0.46g. This value includes also an amplification factor of 3 to take into account the soft soil conditions.

4.2.1.1 Assessment of Seismic Risk

Proper seismic design criteria can be calculated by at first establishing an acceptable level of risk for the proposed building or complex. The analysis of the seismic risk depends on the expected project life and on the probability of occurrence of seismic events, which can be obtained from historical data records.

According to the Centro Migrante executive summary, the housing community should be planned for a total life expectancy of 20 years – including possible disassembly and moving every 5 years. This time frame represents the starting point for the seismic risk analysis bases on historical data records.

The table below shows reference values of probabilities of occurrence of an earthquake with a given return period, T, with respect to the life of the building.

	Building Lifetime, years				
Return Period, T	**10**	**15**	**20**	**25**	**30**
50	18.3%	26.1%	**33.2%**	39.7%	45.5%
100	9.6%	14.0%	**18.2%**	22.2%	26.0%
150	6.5%	9.5%	**12.5%**	15.4%	18.2%
200	4.9%	7.2%	**9.5%**	11.8%	14.0%
250	3.9%	5.8%	**7.7%**	9.5%	11.3%
500	2.0%	3.0%	**3.9%**	4.9%	5.8%
1000	1.0%	1.5%	**2.0%**	2.5%	3.0%

Table 4-1- Assessment of Seismic Risk

The seismic risk, R, can be calculated with the formula:

$$R = 1 - (1 - 1/T)^n$$ (Ang, Tang et al. 2007)

R = risk, T = return period and n = the building lifetime in years

Generally, according to codes (IBC 2003), (UBC 1997) an acceptable level of risk for low-rise residential buildings should be equal to 10%. Therefore, for a life expectancy of 20 years, we should compute the PGA of the 200-year return period event.

4.2.1.2 Assessment of Historic Seismicity

The historic seismic activity in the vicinity of Intramuros in Metro Manila has been assessed with the USGS[27] earthquake database, within the period January 1973- May 2007. The search was performed in order to obtain historical records for seismic events of magnitude larger than 5.0 in a circular area centered on the project site coordinates, 14°35'22.80"N and 120°58'35.11"E. Two searches have been carried out, including earthquakes in an area within 200 km from the site and within 400 km. All the data results, with date, magnitude and distance from the site are included in the appendix C.

The magnitude and the consequent PGA of the 200-year event in Manila area can be obtained with the assessment of these historical records, which provided meaningful data sets to analyze, in order to establish the regression coefficients and calculate the proper recurrence relationships. The Recurrence Relationship has been calculated following Gutenberg and Richter's formula (Gutenberg and Richter 1955), in order to establish the return period of an earthquake of a given magnitude:

$$T = \frac{1}{N} \qquad \text{with} \quad \log N = a - b \cdot M$$

where a and b are the regression coefficients estimated from the sample historical data, N is the average number per year of earthquakes of any given magnitude, M, and T is the Return Period.

[27] US Geological Survey database, www.usgs.gov

4.2.1.3 Geotechnical Condition

According to a report made available by Geotecnica Corporation, an assessment of Intramuros geotechnical condition has been conducted in October 1999 under commission of Philippines Bureau of Treasury (GeotecnicaCorporation 1999).

The site investigation resulted in the calculation of the allowable bearing capacity and the general soil characteristic of the Intramuros area. The drilling exam revealed a thick strata of Quaternary Alluvium (QAI) of very soft to still clayey silt (12-13 meters thickness). According to the report, the soil allowable bearing capacity ranges from a minimum of 85 kPa to a maximum of 11,490 kPa; also, the report states the tendency of the soil to excessive settlements and liquefaction, thus suggesting the use of deep pile foundations, for sensitive structures. Based on these data, we conclude that the area of Intramuros is characterized by a very soft soil, which is a dangerous factor for amplifying seismic excitations.

4.2.1.4 Calculation of Peak Ground Acceleration

Once the level of risk and the return period are calculated, the next step is to calculate the Peak Ground Acceleration with the appropriate Attenuation Relationship. Most of the several attenuation relationships available in the scientific literature (Ambrose and Vergun 1999) have been empirically developed to calculate peak bedrock acceleration at a 10% probability of exceedance and, in the Southeast Asia region, one of the most used and scientifically accepted is the one developed by Fukushima and Tanaka in 1988 (Fukushima, Tanaka et al. 1988). This formula has been set especially for rock soil but can be adapted to soft soil types with the proper amplification factor

$$\log A = 0.41 \cdot M - \log[R(0.032 \cdot 10)^{0.41M}] - 0.034R + 1.30$$

A = peak acceleration (cm/sec^2)

R = shortest distance between the site and the fault rupture (km)

M = earthquake magnitude

Also, a proper amplification factor of 3 - Safety Factor, FS - has been added to take into account soft soil condition.

Magnitude, M	Seismic Risk, R	Return Period, T	Seismic Attenuation A, m/s^2 *Fukushima*	Acceleration magnified by soil factor *Fukushima*
5	100%	0.3	0.02	0.05
5.5	100%	0.8	0.02	0.07
6	100%	2	0.04	0.11
6.5	94%	7	0.06	0.17
7	62%	20	0.08	0.25
7.4	34%	48	0.11	0.32
7.6	24%	74	0.12	0.37
7.8	16%	113	0.14	0.41
8	11%	174	0.15	0.46
8.1	9%	215	0.16	0.49
8.2	7%	267	0.17	0.51
8.4	5%	409	0.19	0.56
8.5	4%	507	0.19	0.58
8.8	2%	964	0.22	0.65
9	1%	1479	0.23	0.70

Table 4-2 Calculation of Peak Ground Acceleration

- *Shortest distance site-fault rupture*

  R = 77 km

- *Regression coefficients* (obtained by historical seismicity data)

  a = 5.20 b= -0.9227

The calculated Peak Ground Acceleration is equal to 0.46g (in m/s^2).

4.2.2 *Calculation of Base Shear*

The most important parameter for a load estimation due to seismic effect, is the base shear, which represents the equivalent static lateral load effect applied to the structure (Ambrose and Vergun 1987), (Ambrose and Vergun 1999). Its value is directly proportional to the building weight and, generally, a lightweight building will have a lower base shear. Most codes contain detailed information for calculating seismic effects on a low rise building; The Philippines National Structural Code also provides to a detailed formulation to calculate the design base shear in any given direction and its results are similar to those obtained with the IBC 2003. The calculation performed for the Base Shear took into account the option of a one-story structure and the two-story options, in order to evaluate the difference in loads.

$$V = \frac{ZIC}{R_w} \cdot W \quad \text{where} \quad C = \frac{S}{T^{2/3}} \cdot 1.25$$

Z = Seismic Zone factor (refer to Table 1 and Figure 1)

I = Importance factor (refer to Table 2 and 3)

R_w = Numerical Coefficient *(refer to Table 4)*

C = Numerical Coefficient *(refer to Figure 2)*

T = Fundamental Period of vibration of structure for the direction under consideration

S = Site Coefficient for Soil characteristics *(refer to Table 5)*

W = Seismic Dead Load (total dead load and applicable live loads – partitions and permanent equipments)

The following tables and figures have been attained from the Philippines National Structural Code, in order to estimate a value for the base shear.

Zone	1	2	3	4
Z	**	0.2	0.3	0.4

Table 4-3 Seismic Zones Factor *Z*[28]

[28] Table associated to Figure 4-1

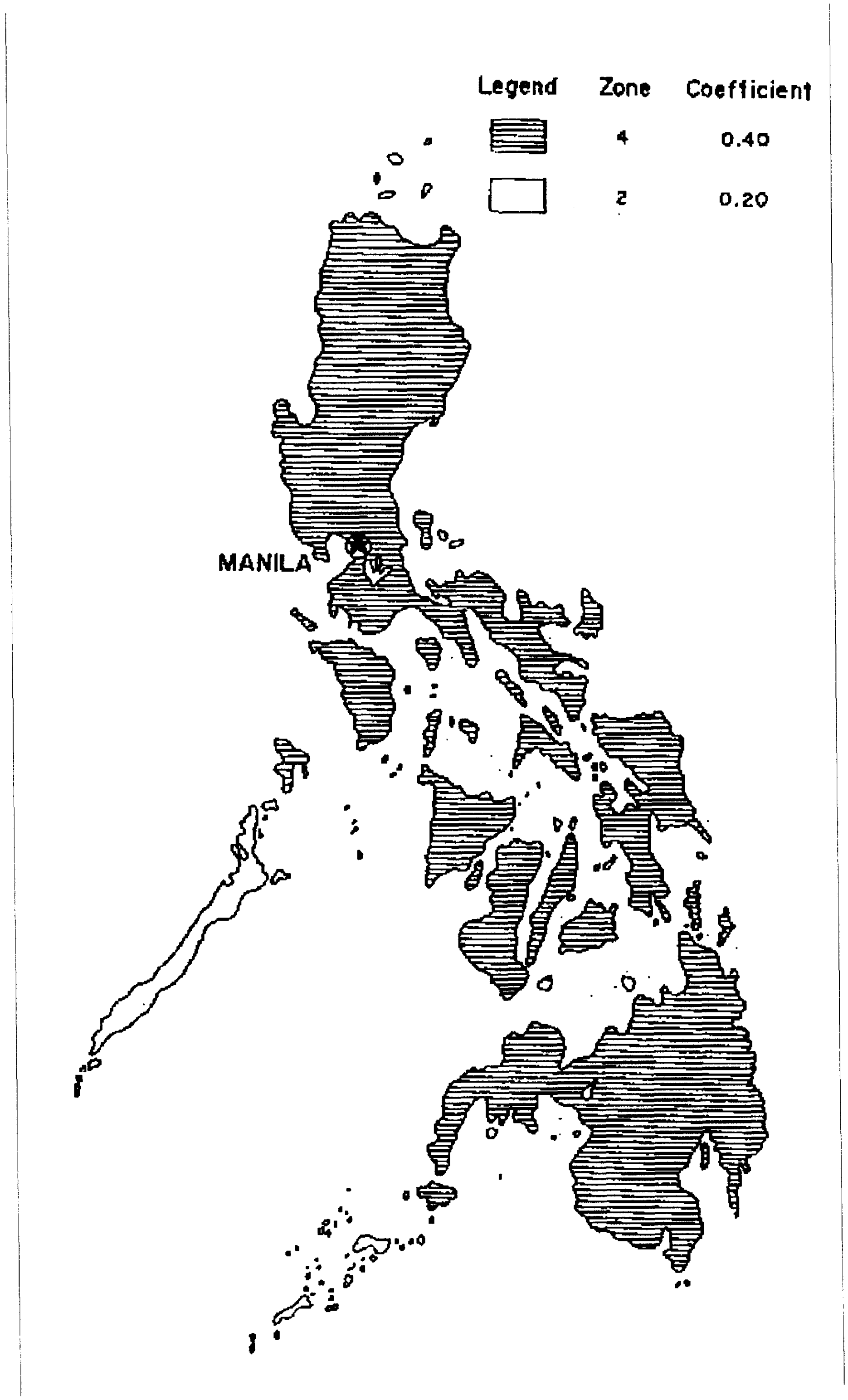


Figure 4-1 Seismic Zones Map

Occupancy Categories	Occupancy Type of Function of Structures
Essential Facilities	• Hospitals and other medical facilities having surgery, and emergency treatment areas. • Fire and police stations • Tanks or other structures containing, housing, or supporting water or other fire-suppression materials or equipment required for the protection of essential or hazardous facilities, or special occupancy structures. • Emergency vehicle and equipment shelters and garages • Structures and equipment in emergency preparedness cneters • Stand-by-power generating equipment for essential facilities • Structures and equipment in communication centers and other facilities required for emergency response.
Hazardous Facilities	• Structures housing, supporting or containing sufficient quantities of toxic or explosive substances to be dangerous to the safety of the general public if released.
Special Occupancy Structures	• Covered structures whose primary occupancy is public assembly-capacity more than 300 persons. • Buildings for schools (through secondary) or day-care centers-capacity more than 250 students. • Buildings for colleges or adult education schools-capacity more than 500 students. • Medical facilities with 50 or more resident incapacitated patients, but not included above. • Fails and detention facilities. • All structures with occupancy more than 5000 persons. • Structures and equipment in power generating stations and other public utility facilities not included above, and required for continued operation.
Standard Occupancy Structure	• All structures having occupancies or functions not listed above.

Table 4-4 Occupancy Categories

Basic Structural System	Lateral Load Resisting System - Description	Rw	Height
A. Bearing Wall System	1. Light Framed Walls With Shear Panels		
	a. Plywood Walls for Structures 3-stories or Less	8	20 m
	b. All Other Light Framed Walls	6	20 m
	2. Shear Walls		
	a. Concrete	6	50 m
	b. Masonry	6	15 m
	3. Light Steel Framed Bearing Walls With Tension-Only Bracing	4	20 m
	4. Braced Frames Where Bracing Carries Gravity Loads		
	a. Steel	6	50 m
	b. Concrete	4	-
	c. Heavy Timber	4	20 m
B. Building Frame System	1. Steel Eccentric Braced Frame (EBF)	10	70 m
	2. Light Framed Walls With Shear Panel		
	a. Plywood Walls for Structures 3-stories or Less	9	20 m
	b. All Other Light Frames Walls	**7**	**20 m**
	3. Shear Walls		
	a. Concrete	8	70 m
	b. Masonry	8	15 m
	4. Concentric Braced Frames		
	a. Steel	8	50 m
	b. Concrete	8	-
	c. Heavy Timber	8	20 m
C. Moment Resisting Frame System	1. Special Moment Resisting Space Frames (SMRSF)		
	a. Steel	12	N.L.
	b. Concrete	10	N.L.
	2. Concrete Intermediate Moment Resisting Space Frames (IMRSF)	7	-
	3. Ordinary Moment Resisting Space Frames		
	a. Steel	6	50 m
	b. Concrete	5	-
D. Dual System	1. Shear Walls		
	a. Concrete With SMRSF	12	N.L.
	b. Concrete With Concrete IMRSF	9	50 m
	c. Masonry With SMRSF	8	50 m
	d. Masonry With Concrete IMRSF	7	-
	2. Steel EBF With Steel SMRSF	12	N.L.
	3. Concentric Braced Frames		
	a. Steel With Steel SMRSF	10	N.L.
	b. Concrete With SMRSF	9	-
	c. Concrete With Concrete IMRSF	6	-
E. Undefined Systems		-	-

Table 4-5 Structural Systems

Occupancy Category	Importance Factor, I	
	Earthquake	*Wind*
Essential Facilities	1.25	1.15
Hazardous Facilities	1.25	1.15
Special Occupancy Structures	1.00	1.00
Standard Occupancy Structures	**1.00**	**1.00**

Table 4-6 Occupancy Requirements

Type	Description	S Factor
S1	A soil profile with either (a) A rock-like material characterized by a shear-wave velocity greater than 760 m per second or by other suitable means of classification or (b) stiff or dense soil condition where the soil depth is less than 60 m	1.0
S2	A soil profile with dense or stiff soil conditions, where the soil depth exceeds 60 m or more.	1.2
S3	**A soil profile 12 m or more in depth and containing more than 6 m of soft to medium stiff clay but not more than 12 m of soft clay**	**1.5**
S4	A soil profile containing more than 12 m of soft clay	2.0

Table 4-7 Site Coefficients

4.2.2.1 Estimation of Building Natural Period of Vibration

According to the section 2.2.5.2.2. of the Philippines NSC, the Natural Period of vibration can be calculated with the following formula:

$T = C_t (h_n)^{3/4}$

C_t = 0.050 for all non-concrete and non-steel structures
h_n = building height in meters

One-story unit option T = 0.050*3 = **0.15 seconds**
Two-story unit option T = 0.050*6 = **0.3 seconds**

4.2.2.2 Calculation of Factor C

S = 1.5 soil factor according to Table 5

$$C = \frac{S}{T^{2/3}} \cdot 1.25$$

One-story unit option **C = 6.642** Two-story unit option **C = 4.184**

These values may be too conservative, but the following formulas are defined by the Philippines code and ought to be observed.

4.2.2.3 Calculation of Design Base Shear

Z = Seismic Zone factor = 0.4 I = Importance factor = 1

R_w = Numerical Coefficient = 7[29]

Given all the conditions and numerical coefficients above, the calculation of base shear according to the Philippines National Structural Code can be performed as follows:

One-story option

$$V_1 = \frac{ZIC}{R_w} \cdot W = \frac{0.4 \cdot 1 \cdot 6.642}{7} \cdot W = \mathbf{0.38\ W}$$

Two-story option

$$V_2 = \frac{ZIC}{R_w} \cdot W = \frac{0.4 \cdot 1 \cdot 4.184}{7} \cdot W = \mathbf{0.24\ W}$$

[29] The value for R_w is taken from Table 4-5, section B (building frame system) and corresponds to the value set for light framed walls with shear panels not made of plywood.

4.2.3 Wind Loads

Most codes provide certain procedures for calculating the effect of wind loads on a structure. The procedure recommended by the Philippines National Structural Code, contained in section 2.57, resembles the one contained in the IBC 2003, based on the ASCE standard 7-02. The basic wind pressure formula is the following:

$$P = C_e \cdot C_q \cdot q_s \cdot I$$

P represents the Design Wind Pressure, C_e is the exposure coefficient, Cq is a form coefficient, I is the importance factor (equal to 1 for residential buildings) and q_s is the basic wind speed. The Philippine Code sets, q_s, the wind speed design value for Manila at 175 km/h (which is equivalent to a pressure q_s of 1500 Pa). However, according to the more recent data gathered by the Pacific Disaster Center in 2007, the wind speed design value in Manila should be set to 210 km/h, which equals a q_s of 2000 Pa.

The basic wind design pressure for both one and two stories have been calculated, and the results are summarized in the tables below.

DESIGN WIND PRESSURE (Pa)

	Extreme Wind		Strong Wind	
	1-story	*2-story*	*1-story*	*2-story*
Leeward Wall	630	670	472.5	502.5
Windward Wall	1008	**1072**	756	**804**
Windward Roof	504	536	378	402
Leeward Roof	882	**938**	661.5	**703.5**

Table 4-8 Wind pressure in Pascal

DESIGN WIND PRESSURE (psf)

	Extreme Wind		Strong Wind	
	1-story	*2-story*	*1-story*	*2-story*
Leeward Wall	13.2	14.0	9.9	10.5
Windward Wall	21.1	**22.4**	15.8	**16.8**
Windward Roof	10.5	11.2	7.9	8.4
Leeward Roof	18.4	**19.6**	13.8	**14.7**

Table 4-9 Wind pressure in psf

PART THREE:

<u>PROJECT DEVELOPMENT</u>

CHAPTER V

5 The Design: Housing Units layout and Building Systems

5.1 Architectural Design

For this type of housing, the local architecture of the Bahay Kubo has been reconsidered and engineered with modern structural solutions. The typical Filipino hut has been redesigned with bamboo compound columns, sawali partition walls and nipa roof and engineered with earthquake resistant shear walls and stiffened elements for wind loads.

5.1.1 Site Layout

The architectural layout has been developed according to the requirements outlined in the previous chapter. The project site has been studied through the material provided by Centro Migrante and other useful tools as GIS system and GoogleEarth.

Wind and Solar orientation drove the project development, in order to locate the units along the prevailing wind directions and take maximum advantage of passive cooling through natural ventilation.

The need of improving natural air circulation should call for an urban scattered configuration, which can allow more easily the air passage. Nevertheless, in Metro Manila area, the land is precious and expensive a compromise should be reached in order to find a proper balance between land use and architectural requirements.

In this perspective, the proposed layout is meant to reach this balance by joining two SOUs as a single block; each block is offset and "mirrored" in respect to the adjacent blocks, in order to maximize the possibility of openings.

All coupled SOUs share a full length structural wall, the roof, the floor raised platform and their entrance face the same directions, while SOUs of different blocks share a short structural wall. Circulation space will allow entrance to units and will connect to the public administration buildings.

5.1.2 Single Occupancy Unit (SOU) Layout

Each SOU has an area of $6m^2$, 2 per 3 meters and it is composed of 2 basic modular units, measuring 1x1.5 m.

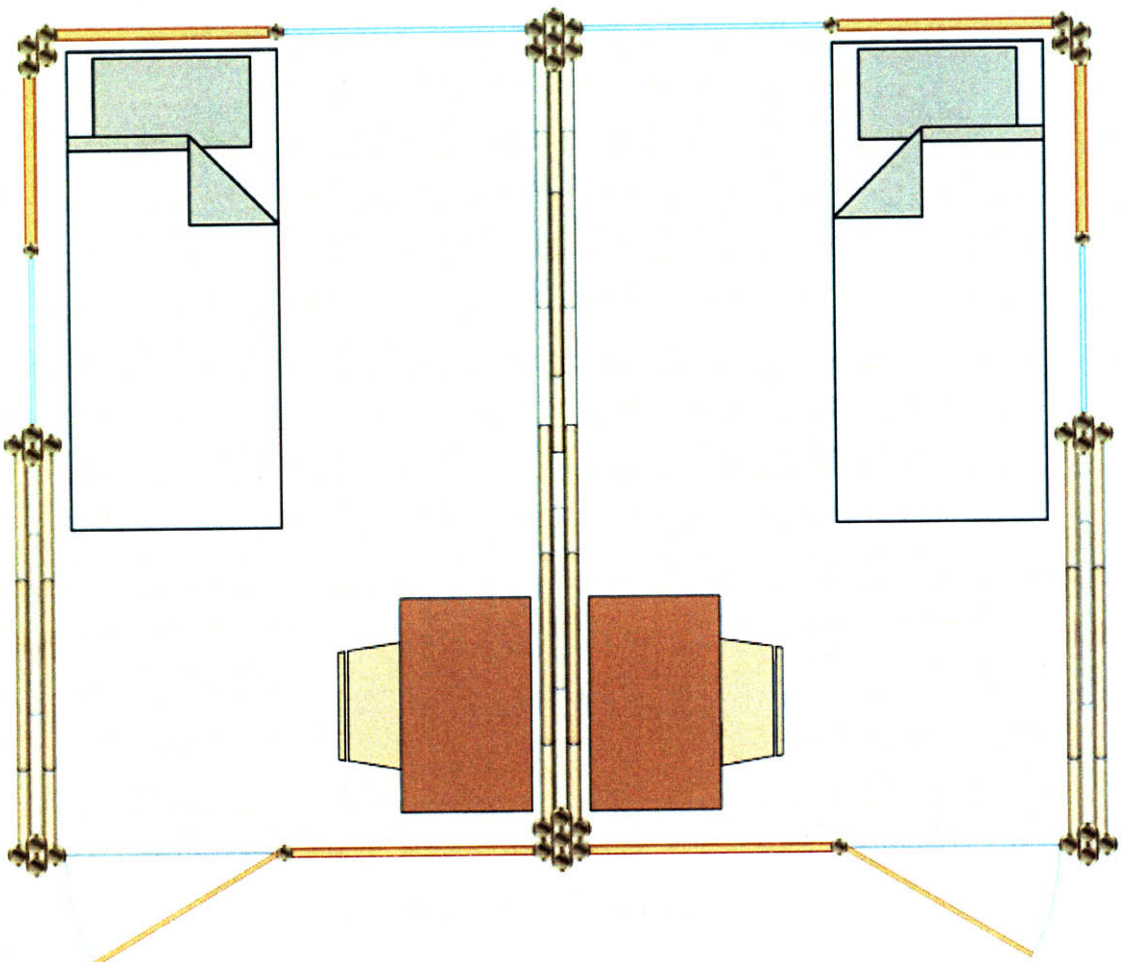


Figure 5-1 Plan of 2 adjacent SOU

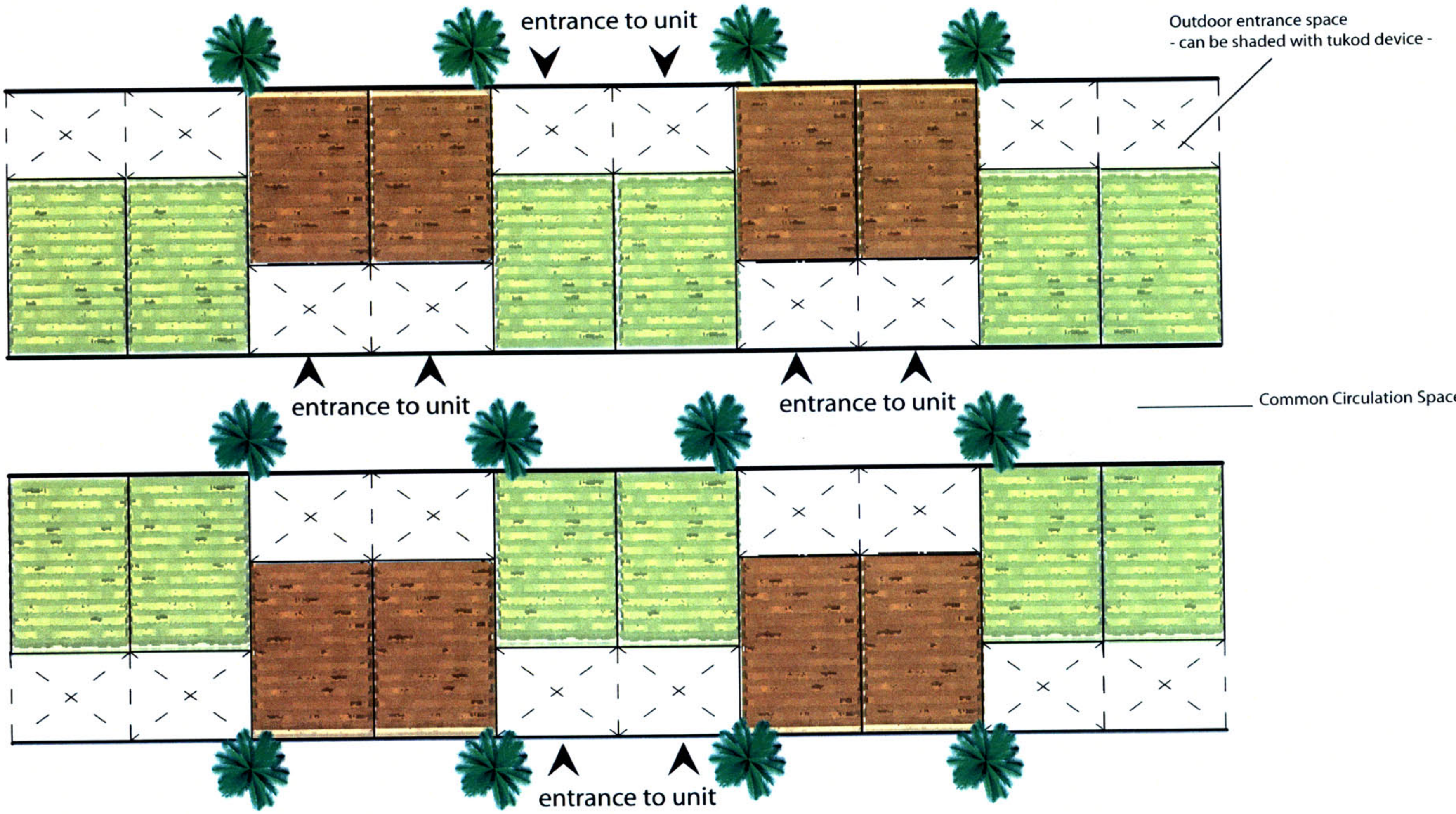


Figure 5-2 Units Layout

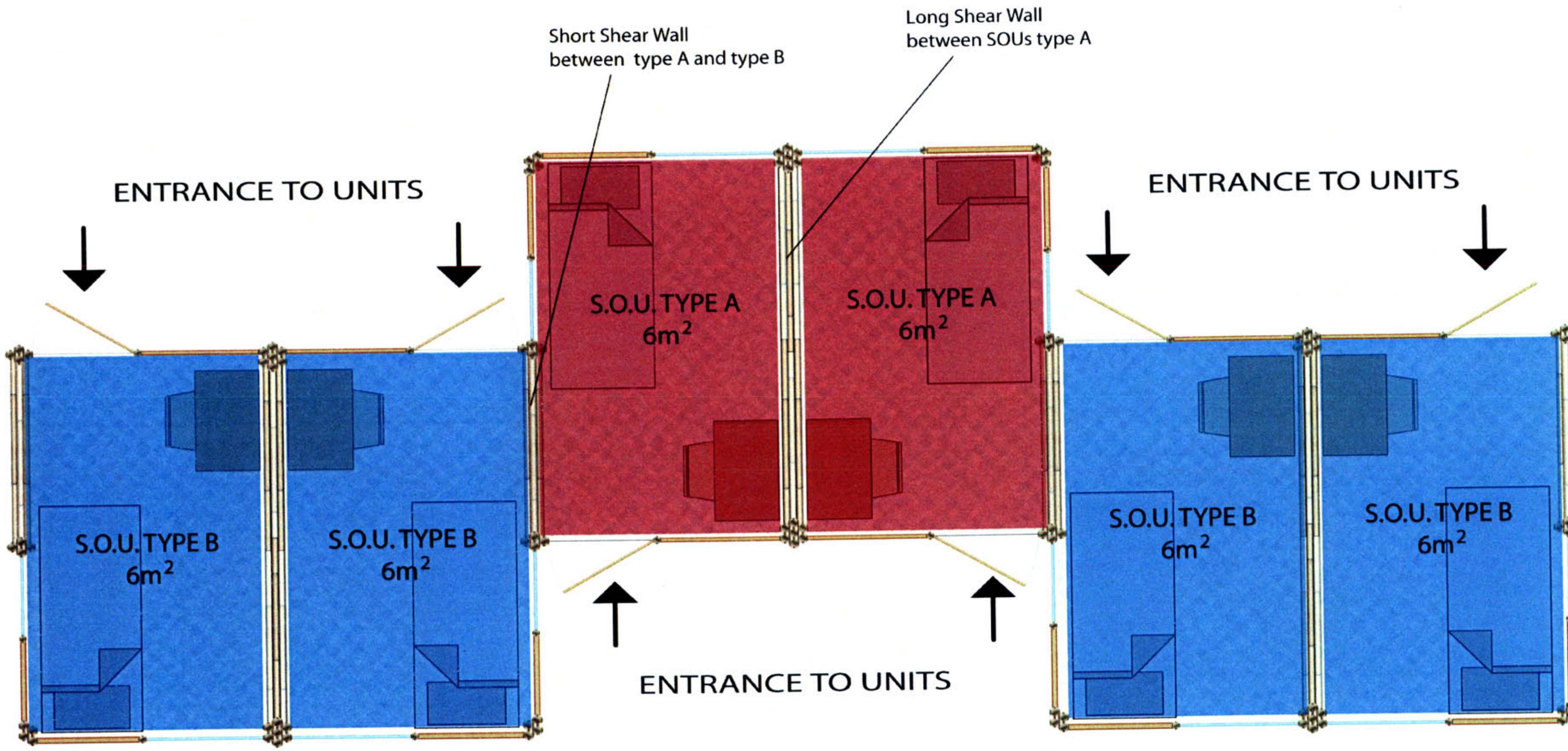


Figure 5-3 SOUs layout scheme

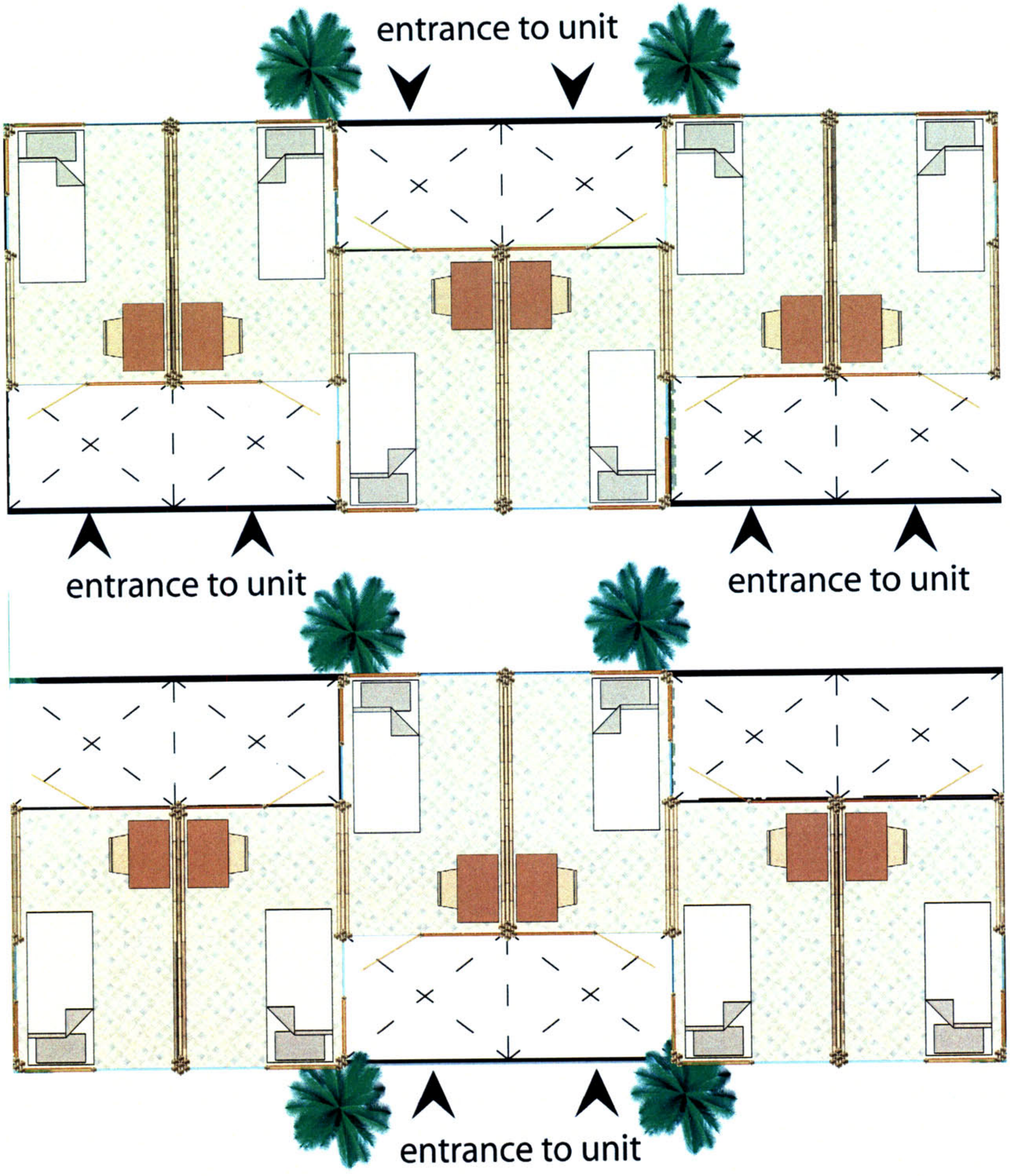


Figure 5-4 Further view of units layout

5.2 *Internal Comfort features*

Heating

Given the climate characteristics of Manila, there is no need for heating, and the walls could be non-insulated.

Ventilation

Every SOU is provided with two windows, in addition to the entrance door. These openings cover a total warea of 3.84 m^2, correspondent to the recommendations outlined in the Mahoney Tables.

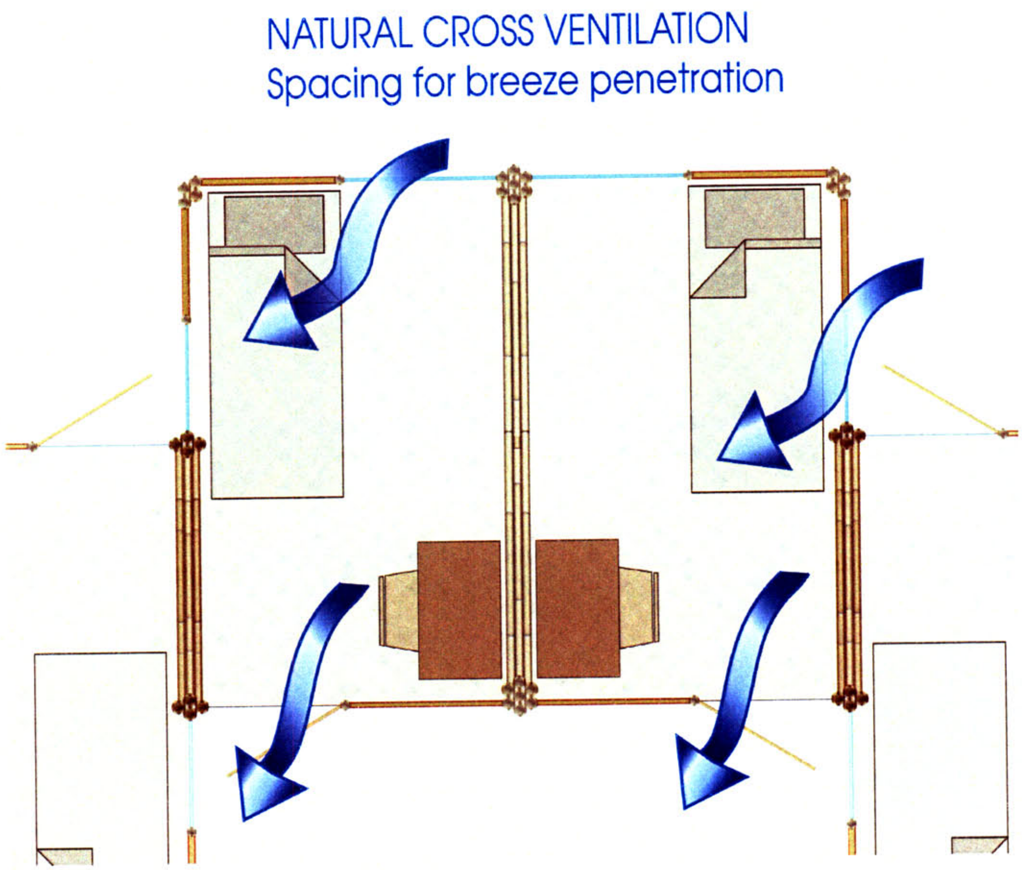


Figure 5-5 Ventilation Scheme

Shading

A modern version of the tukod overhanging offers shadow and avoidance of direct sunlight to each SOU entrance, within the outdoor space. In addition, vegetation along the common circulation space will provide further shading.

Cooling

The cooling system is not provided with any type of mechanical system. As pointed out in chapter 3, the particular climate condition of Manila does not allow the use of nighttime cooling through the use of thermal mass. Hence, passive cooling could be achieved only with natural cross ventilation, porous partition walls and avoidance of direct sunlight.

Daylight

The openings should provide enough diffuse natural light for each SOU.

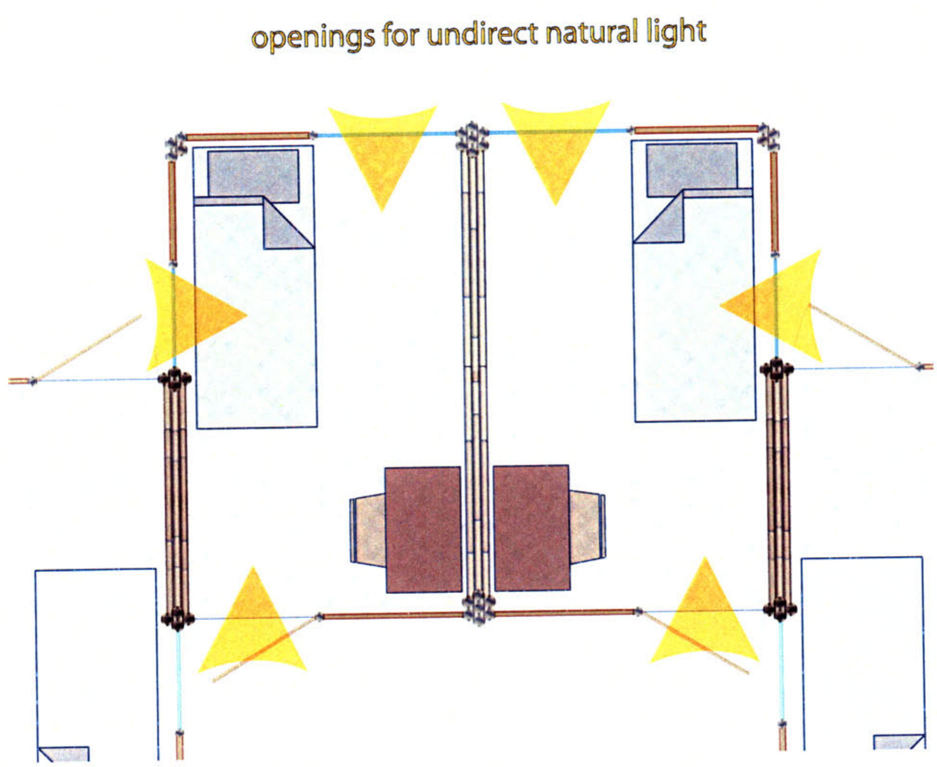


Figure 5-6 Daylight scheme

5.3 Local Materials

5.3.1 Bamboo

Bamboo is the main structural materials of the projects and it has been used for the structural frame – compound columns, beams, bracings – and for the roof trusses. A full and complete research about the material characteristics has been carried out prior to the design development and further details are available in the appendix.

Bamboo has several inherent advantages: it is inexpensive and locally available in many developing countries locations, it is intensively renewable and possesses a low embodied energy; it can grow faster up to 15 meters in its first year. Bamboo seems to represent a viable and sustainable solution of housing problems around the world. Houses made out of this material are low cost, environmental friendly, easy to construct, durable, flexible, socially adaptable and resistance to earthquake.

However, some disadvantages have to be considered and fully evaluated prior to design development phases, in order to minimize possible negative effects.

- tendency to split when dry
- diameter and dimension varies
- imperfection of culms
- sensitivity to insects and mold
- requires special preservation treatments

Since bamboo physical and mechanical properties may vary significantly according to single species and location, several literature sources (Hidalgo 2003), (Villegas 2003), (de Vries 2002), (INBAR, 2007) have been consulted to have suitable design parameters for bamboo used in the Philippines for building construction. The following table summarizes the compared properties of Structural Steel and Bambusa Vulgaris, the main Filipino bamboo species used in building construction. Full data are available in the appendix and further information about Filipino species is available in the appendix.

	Density	Units	Compressive Strength	Tensile Strength	Modulus of Elasticity	Modulus of Rupture
Bambusa Vulgaris	630	kg/cm^2	455	1,322	76,205	1,147
	kg/m^3	psi	6,470.1	18,798.84	1.09×10^6	16,310.34
Steel ASTM A36	7,800	kg/cm^2	2,549.3	4,079	20.4×10^4	4,079
	kg/m^3	psi	36,260	58,000	29×10^6	58,000

Table 5-1 Bambusa Vulgaris properties[30]

In order to use bamboo as a structural material for Centro Migrante, a specific preservation treatment should be performed prior to site work. This is to ensure the material duration for construction purposes (Janssen 1988) (Liese, Gutierrez et al. 2002), (Villegas 2003), (Hidalgo 2003).

5.3.2 Sawali

Sawali is a Filipino term indicating woven bamboo mats. Used as partition walls, sawali panels provide a ventilated and porous skin, which can implement the air circulation inside each SOU.

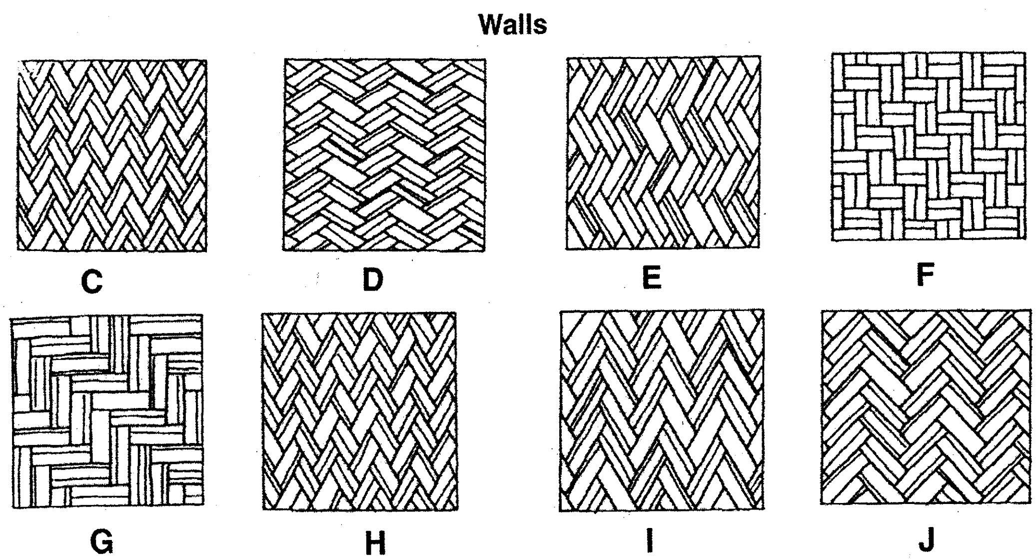


Figure 5-7 Sawali weaving patterns[31]

[30] From Hidalgo, O. (2003). Bamboo the gift of the goods. and Janssen, J. J. A. (1988). Building with bamboo : a handbook. London, Intermediate Technology Publications.
[31] From Hidalgo, O. (2003). Bamboo the gift of the goods.

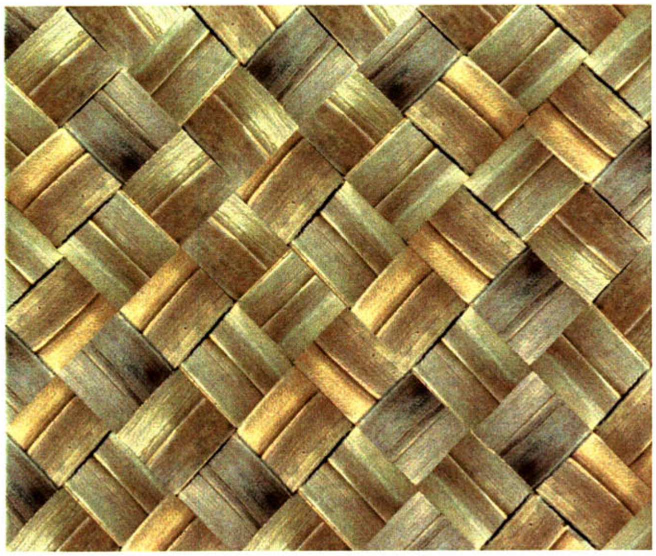


Figure 5-8 Example of Sawali

5.3.3 Plybamboo

Bamboo plywood – called plybamboo or plyboo - is one of the several manufacturing products of bamboo and, similarly to normal timber plywood, it is made of bamboo strips laminated together using a hot press process with a low VOC adhesive.

Figure 5-9 Plybamboo panel[32]

According to some studies (Gonzalez, 2004) plybamboo walls possess inherent structural stiffness against lateral loads, providing the same function of bracing systems or shear walls. However, plybamboo panels represent a more expensive solution, in terms of

[32] Information from www.plyboo.com

actual cost and embodied energy, since their manufacturing process involves more energy consumption.

5.3.4 Capiz Shell

Capiz[33] is both a geographical location and the name of a shell that is used largely in interior decorating and for decorative gifts and accessories. Capiz shell is a native Filipino material, a flat, semi-transparent shell with a pearlescent appearance, and it is the outer shell of the marine mollusk, *Placuna placenta*, found in the shallow coastal waters of the Philippines.

Figure 5-10 Capiz Shell[34]

Nowadays, capiz shell is often used to create elegant decorative objects and items for interior designs but, being a local traditional material, it has been used for several crafted objects, including windows and doors.

Therefore, Centro Migrante SOUs may employ this material as a more economic solution for openings, a viable alternative to glass materials.

[33] Capiz is also the name of a province of the Philippines, facing the Sibuyan Sea to the north

[34] Image available from the Internet, unknown specific source.

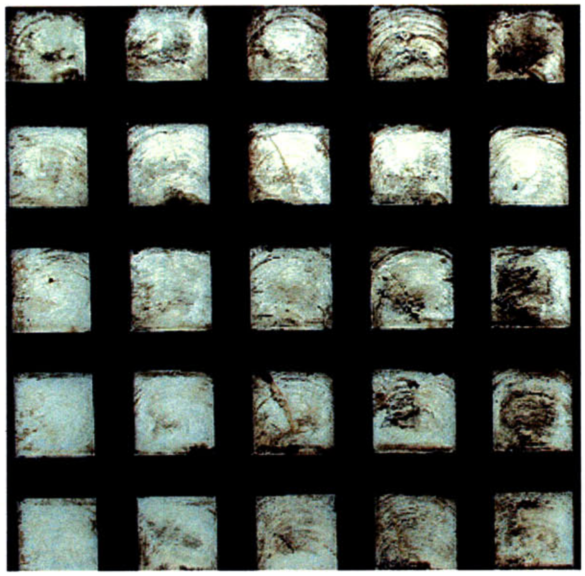


Figure 5-11 Capiz shell window[35]

5.3.5 Nipa leaves

The long, feathery leaves of the Nipa palm are the traditional material for roof cover in the Philippines and they have been used for centuries for the Bahay Kubo.

Figure 5-12 Huts with nipa roof[36]

[35] Image available from the Internet, unknown specific source.
[36] Image available on www.imagesphilippines.com

5.4 Structural System

Regarding the load bearing system for each unit, a comprehensive solution has been studied in order to provide each unit with an efficient gravity load and lateral load bearing system. Also, the proposed layout minimized the number of single wall for each unit and several main structural elements are shared among the units.

The structural system is based upon the concept of a simple frame with stiffened elements such as floor and ceiling diaphragms, bracings, roof trusses, all covered by non-structural wall panels. The efficient mechanical properties of bamboo, in compression, tension and bending, (Janssen 1988), (INBAR, 2007) allow its use for every element of the structural system, columns, beams and bracings.

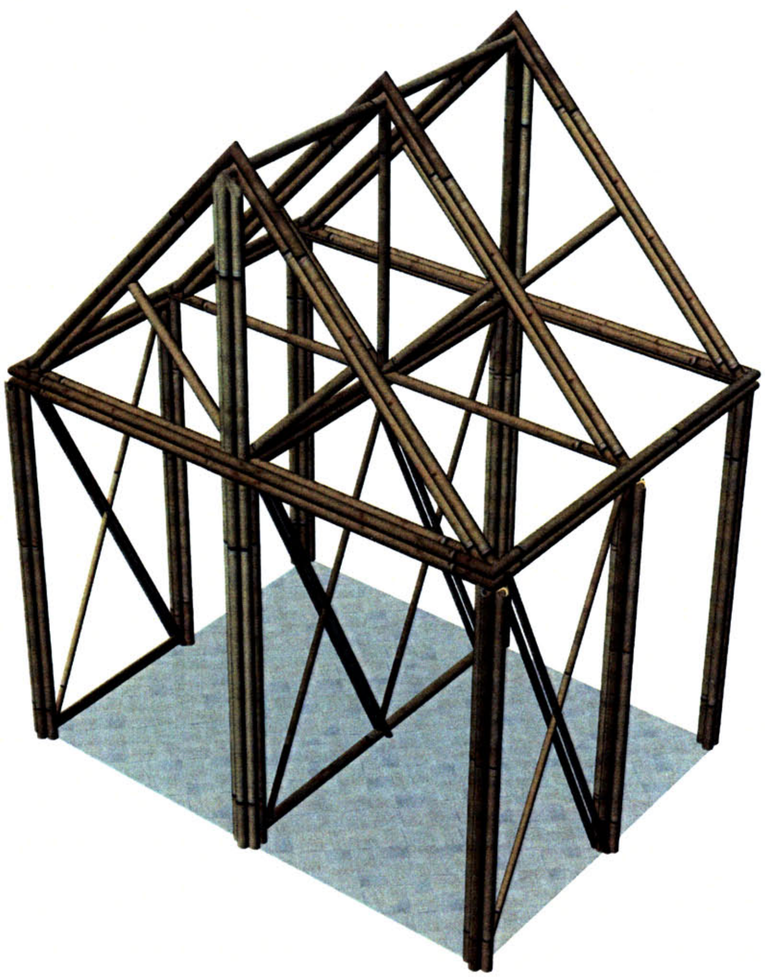


Figure 5-13 Beam-Column frame, Shear Walls and Roof

The whole house system is based upon the use of bamboo of most of its elements.

Core elements

Bundled bamboo columns coupled with double horizontal beams provide the core structural elements of gravity load bearing system. According to the calculation performed, each bamboo pole should have a diameter of 8 cm, with at least 1.5cm wall thickness.

Raised platform

The use of a raised floor facilitates water drainage underneath, provides healthier ground, allows air passage and ventilation and avoids the contact of bamboo with ground. Also, the floor itself is not heated by the ground, following the passive cooling measures described in the previous sections.

Lateral Force Resisting System (LFRS)

The system is comprised of shear walls and stiffening elements for the beam-column corners (knee bracing).

In summary, three main innovative structural solutions have been studied for the project

- Shear Wall system
- Knee Bracing
- Compound Bamboo Column

These systems have been developed not only to fulfill structural problems but also to couple with the other project requirements, namely the easy assembly-disassembly, the presence of prefabricated parts, the use of bamboo as a structural materials and the architectural layout.

5.4.1 Shear wall

Shear walls comprise the vertical elements in the lateral force resisting system (LFRS) for many structures. They support the horizontal diaphragms and transfer the resultant forces from the applied lateral loads into the foundation. A shear wall is essentially a deep, thin cantilevered beam projecting from the foundation that is subjected to one or more lateral forces, such as those due to wind or seismic activity. As the name implies, the basic form of resistance is that of a shear-element and its elements are supposed to provide the structure with the proper shear rigidity. The proposed shear wall system for Centro Migrante is the core element of the Lateral Forces Resisting System and its main function is to withstand seismic loads and to absorb the Base Shear, calculated according to the Philippines National Structural Code. This seismic function is fulfilled by a system of three braced units, shared among different SOUs. Each braced units has a pin connection which allows the system to act as a scissor hinge, easy to mount and dismount. This system is comprised of three main elements, a long shear wall, which is supposed to take half of the total base shear and two shorter walls, which share the remaining load.

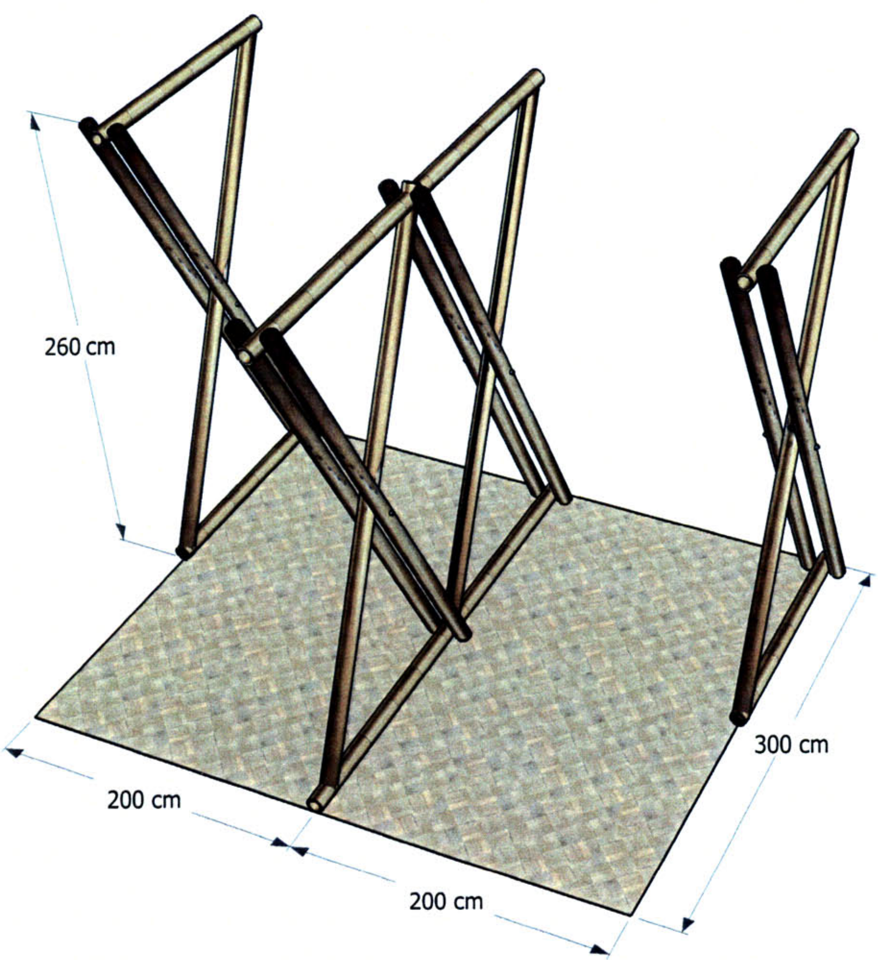


Figure 5-14 Shear Walls System of two coupled SOUs

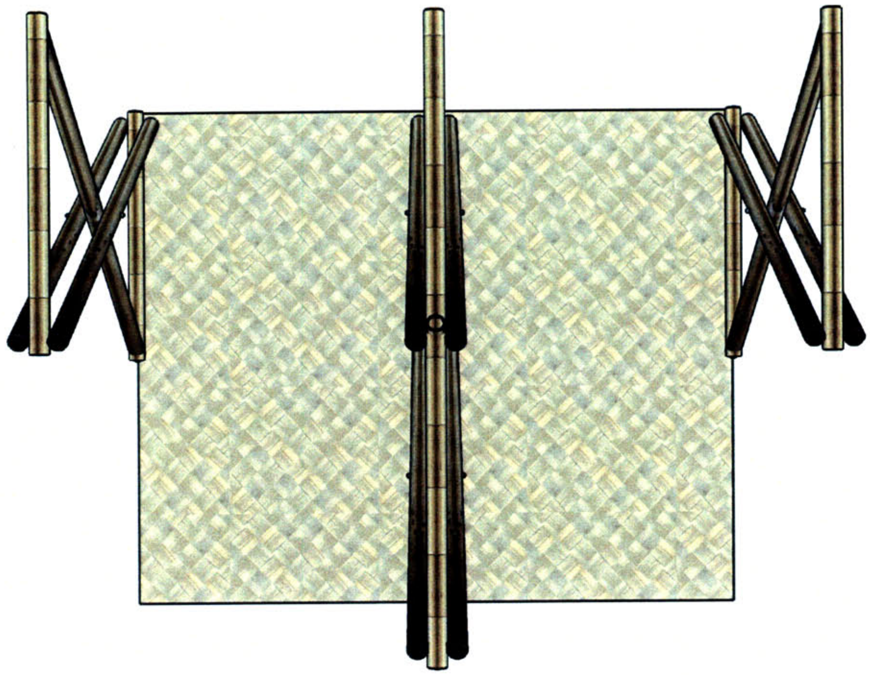


Figure 5-15 Shear Wall plan

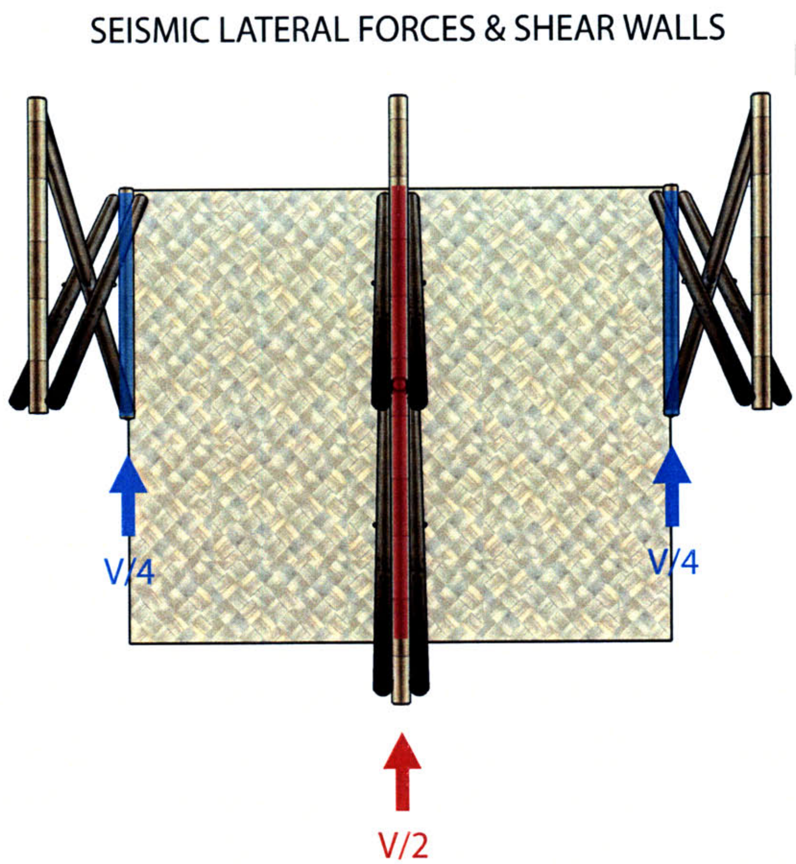


Figure 5-16 Subdivision of Base Shear

With this conceptual scheme and the calculated value of base shear, it is possible to perform further calculations and check the size required for the bamboo culms. The required diameter for the bamboo poles is 7 cm and full detailed calculations are available in the appendix.

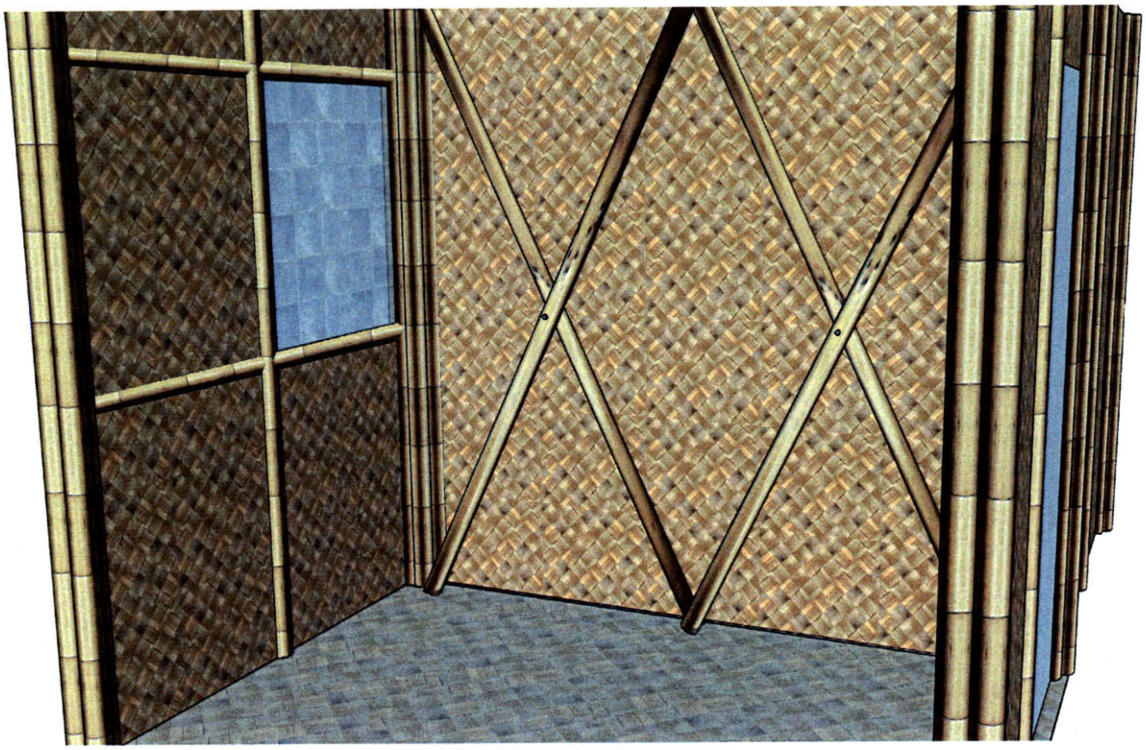


Figure 5-17 Internal View with the long Shear Wall

5.4.2 *Knee Bracing*

This system has been developed to offer further stiffening to the whole frame system in case of strong winds and typhoons. It collaborates with the shear wall system to complete the LFRS (Lateral Force Resisting System) and permits the correspondent beam-column joint to be analyzed as a moment connection, rather than a hinge connection (Diacon 1992), (Gerasimidis, 2006).

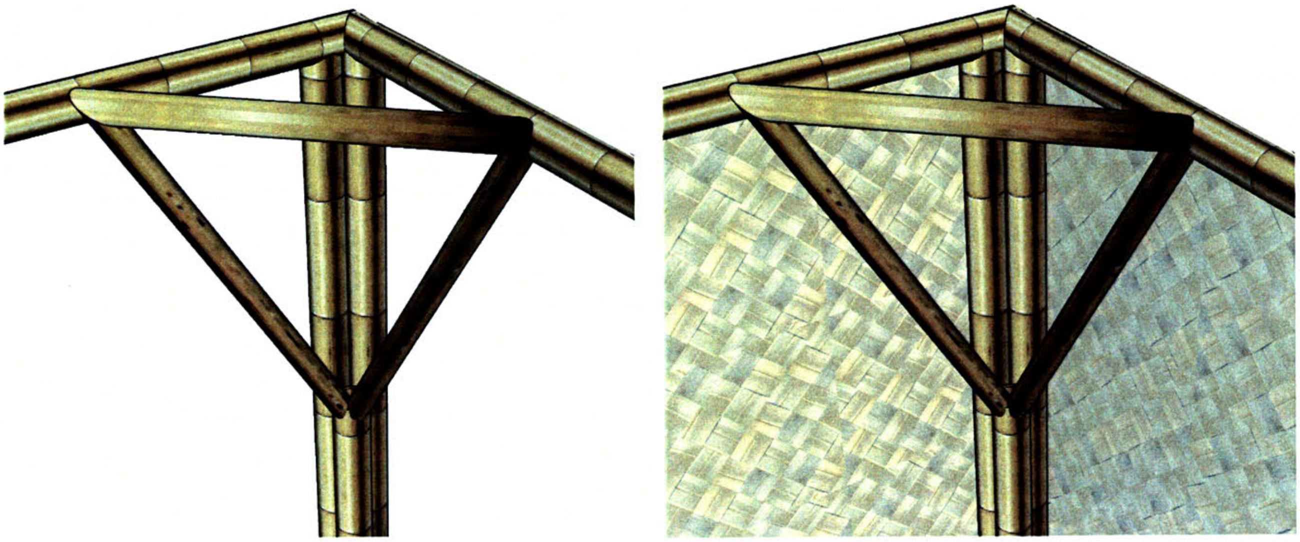


Figure 5-18 Knee Bracing

5.4.3 Compound Columns

Bamboo culms have generally a diameter ranging from 5 to 13 cm, depending on species and location. Bambusa Vulgaris, the species chosen for the project, can be found usually in diameter of 6-10 cm with maximum of 12 cm. Given these small diameter values, the main structural elements, beams and columns should be assembled as compound members, in order to reach the required dimension and stiffness. The configuration of a compound bamboo column can take various shapes, according to functional, structural and aesthetic needs.

The compound column satisfies a structural need by obtaining a larger structural element and the forces can be distributes along the single component, thus creating an effect similar to the pillars of gothic cathedral. The configuration geometry can be adjusted and still creating a global sense of structural clarity. Also, among the benefits of bamboo compound columns, there is the recycling. Bamboo poles can be recycled, treated with special preservations methods and joined together.

Figure 5-19 Compound Column in Simon Velez's ZERI Pavilion[37]

The compound columns system offers a design response to the issue of easy assembly-disassembly on a structural point of view, since every pole possesses a specific function and, together, they are the core of the gravity load-bearing systems.

According to the structural calculations, a diameter of 8 centimeter per pole will offer full resistance to loads – mainly lateral – even taking into account the additional loads for a possible second story. The poles can be joined together with lashing or galvanized wire.

[37] Vegesack, A. v., M. Kries, et al. (2000). Grow your own house : Simón Vélez und die Bambusarchitektur = Simón Vélez and bamboo architecture. [Weil am Rhein, Germany] Vitra Design Museum

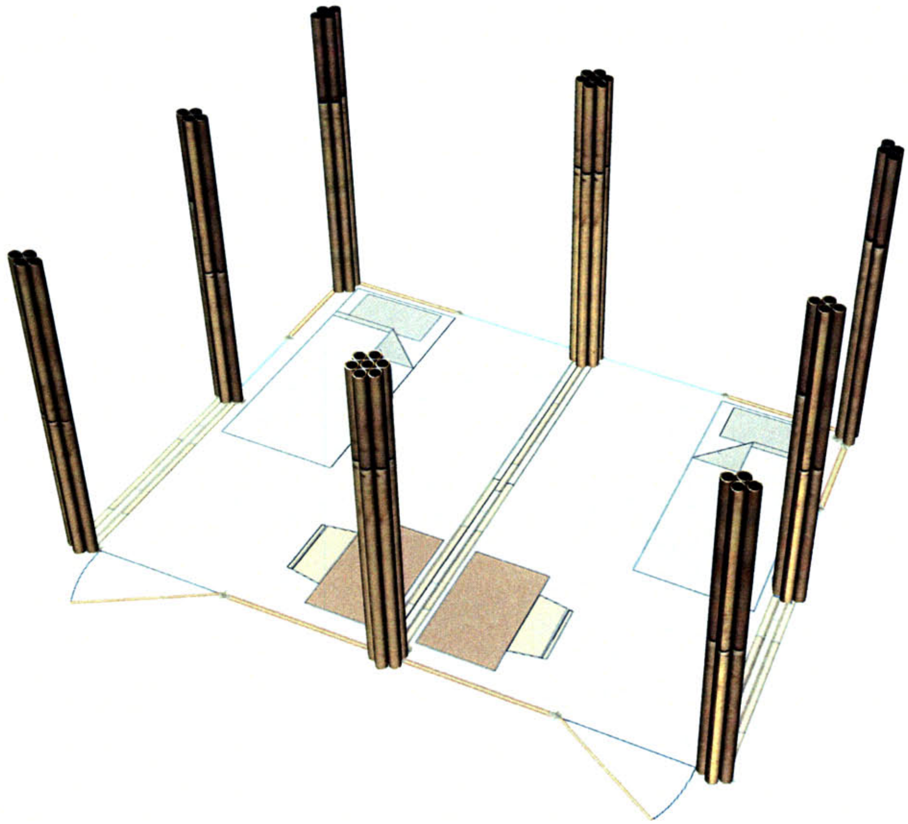


Figure 5-20 Compound columns scheme

5.5 *Wall Paneling*

The partition walls, aimed to fulfill non-structural requirements, have been conceptualized as a series of basic types of modular panels, which can be plain, with a window or a door. These panels are all prefabricated and then mounted on site, joined with the compound bamboo columns.

According to different systems choice, three options have been evaluated for the prefabricated panels: sawali wall, horizontal bamboo culms and plyboo board wall. Upon careful evaluations, sawali panels have been chosen for partition walls, although they require more maintenance and replacement than the other two options. This option creates a porous wall structure, promoting natural ventilation.

Material	Embodied Energy	Cost	Maintenance	Assembly
Sawali	Low	Low	High	Easy
Plyboo	High	High	Low	Medium
Horizontal culms	Low	Low	Medium	Difficult

Table 5-2 Wall partitions evaluation matrix

Anyway, the basic concept of self-help housing, embedded in Centro Migrante, will permit an efficient care of the wall partitions, which should be replaced every year or half-year (INBAR, 2007).

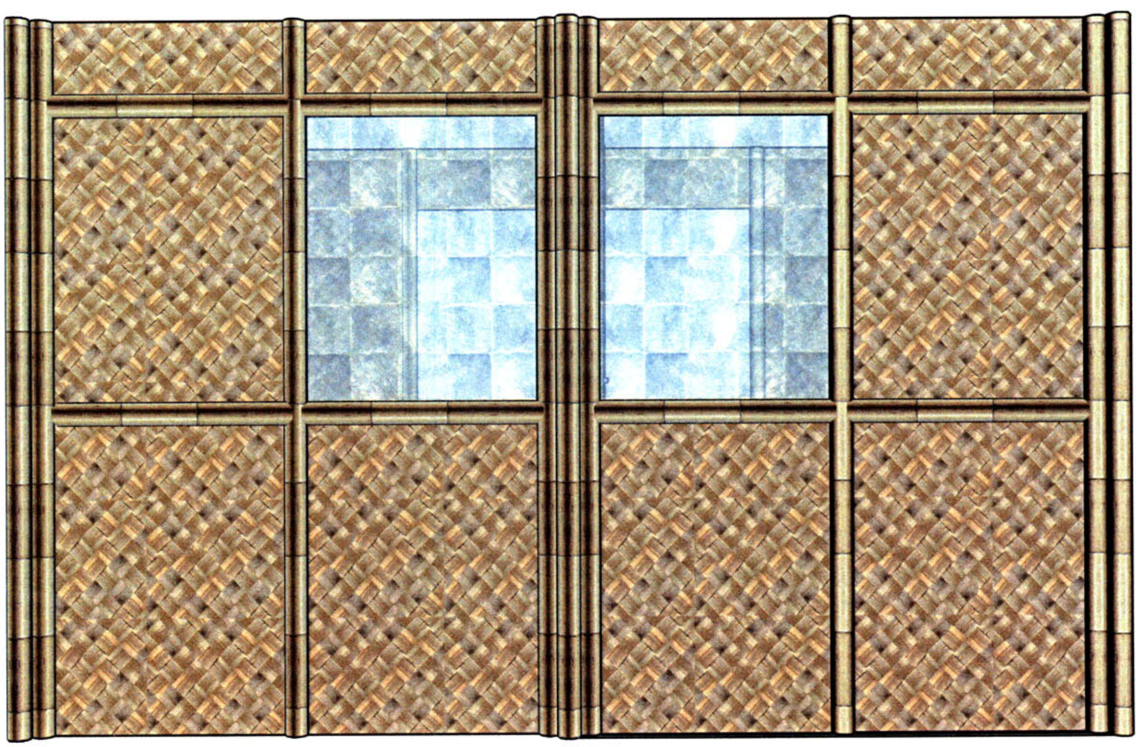


Figure 5-21 Back Elevation of two couples SOUs (Sawali panels option)

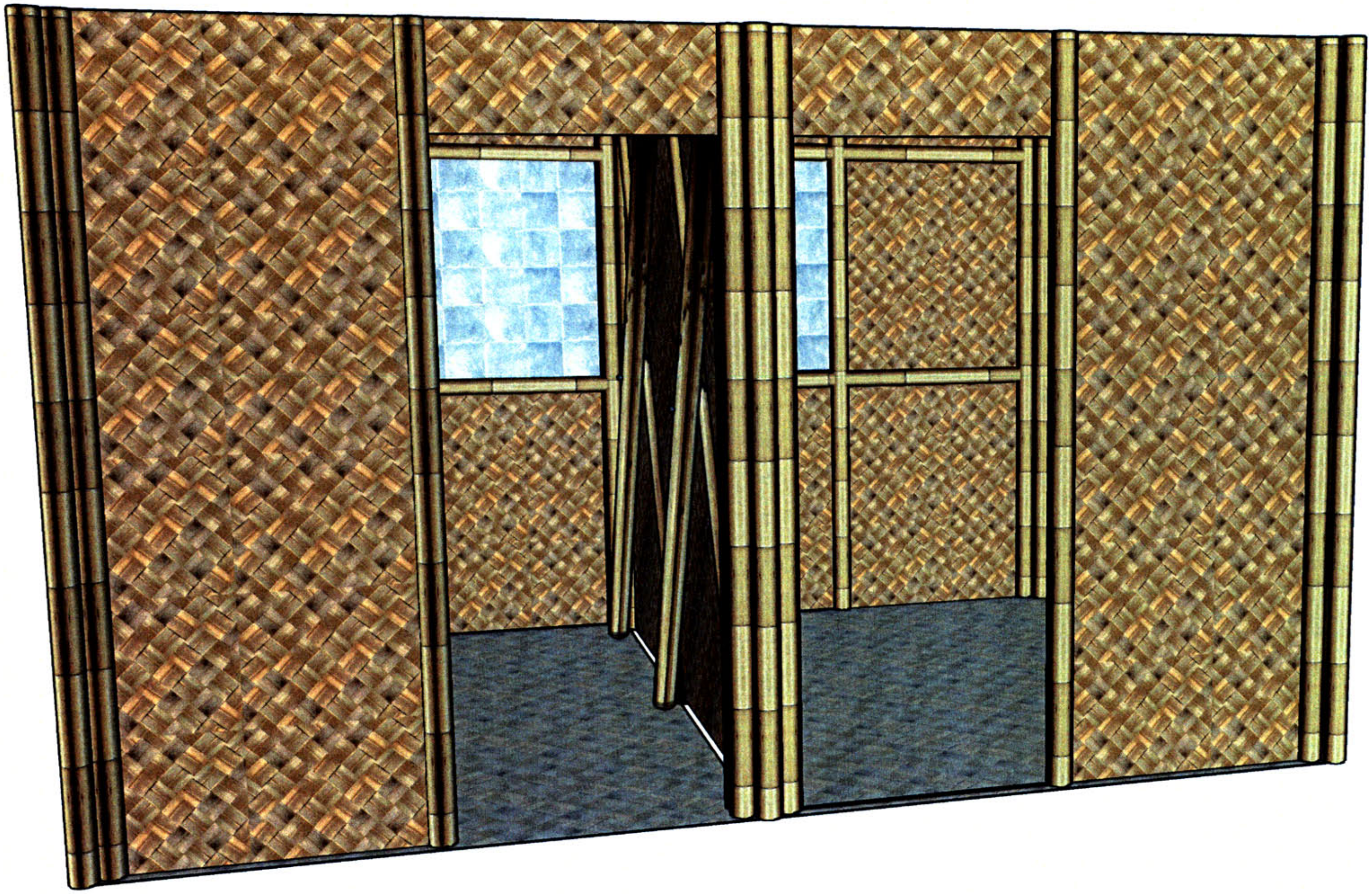


Figure 5-22 View of the entrance

5.6 Foundation System

According to the geotechnical information provided by Centro Migrante (GeotecnicaCorporation 1999), the soil condition[38] of Intramuros should call for a deep pile foundation systems, given the presence of soft clay. However, this solution has been discarded for two main reasons:

deep piles foundations could be problematic if made with bamboo or wood, due to problem of early degradation (the site is also close to the ocean)

the fabrication is more time consuming and expensive, especially if not made with bamboo

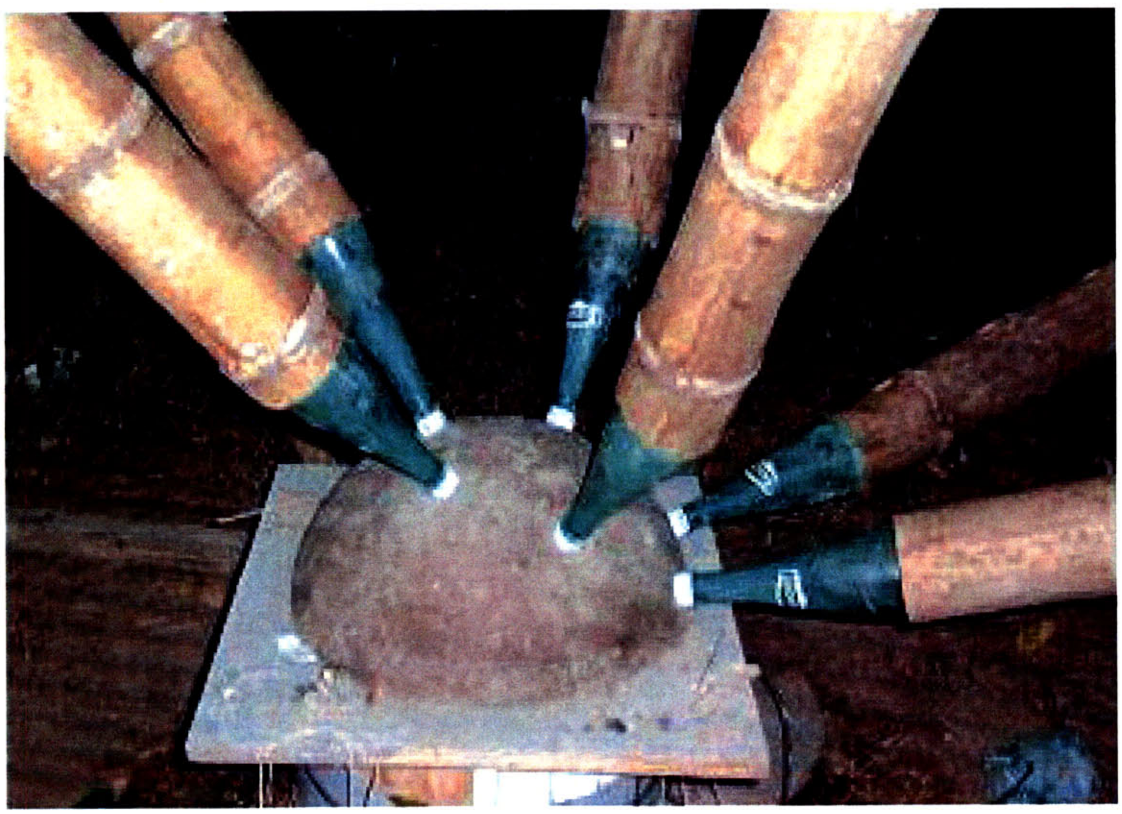


Figure 5-23 Bamboo-concrete foundation with plastic bottles

[38] Refer to Chapter 4

Figure 5-24 Other example of concrete-bottle-bamboo foundation

Generally speaking, Bamboo in contact with soil has a very low lifetime and it is subjected to a process of fast degradation (Janssen 1988), (Janssen 2002). Hence, the alternative solution proposed consists in simple concrete footing coupled with bamboo poles and plastic bottles as tips, filled with mortar cement.

This system has been successfully used by Simon Velez (Vegesack, Kries et al. 2000), and Marcelo Villegas in South America (Villegas 2003), and proved to be efficient both on an architectural and structural point of view. The use of plastic bottles in Centro Migrante could be a way to introduce recycled content in the construction and to easily connect the concrete footing and the bamboo poles.

5.7 Roof System

5.7.1 Structure

Given the large quantity of annual precipitation, the roof should be a high-pitched system. The roof slopes will allow to collect rainwater and harvest it for toilet needs.

The roof structure covers two adjacent SOUs and consists of a system of three prefabricated trusses, which are joined to the beams. This solution has the possibility of temporary removing the trusses, while adding a further floor, and then repositioning them once the second story is in place.

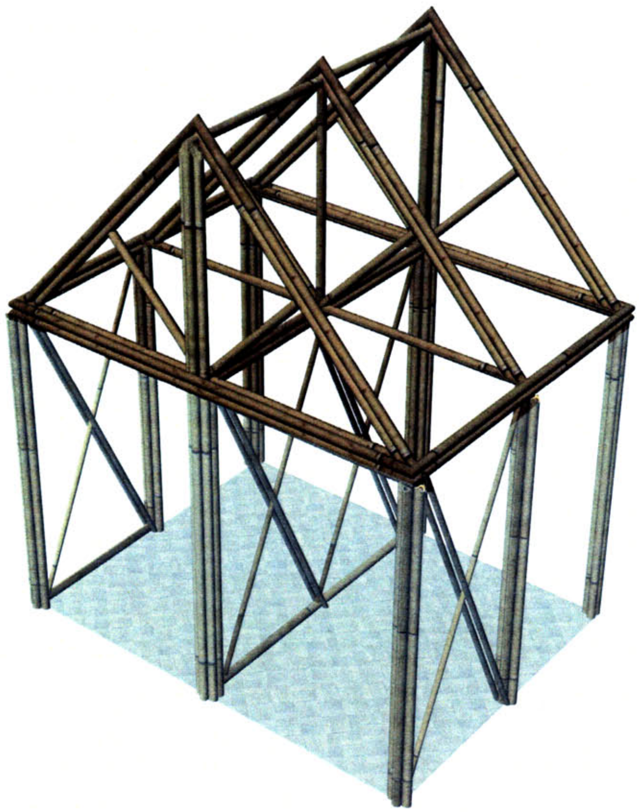


Figure 5-25 Roof Trusses

5.7.2 Covering

The roof cover can be made of bamboo half culms, arranged according to a "Spanish Tile" method, or it can be a thatched roof, covered with nipa leaves. The nipa leaves constitutes a traditional method of roof covering, cheaper and easy to mount; the bamboo culms arrangement, however, is more resistant and should require less maintenance than nipa leaves. In addition, a roof cover with bamboo culms would not absorb rainwater, which could flow down the high slope and be collected through a system of pipes. For all these reasons, the bamboo culms method has been chosen as a cover option. Also, an opening on the roof should be provided to assure flow of exhaust air through stack effect.

5.7.3 Waterproof devices

The roof system has to be provided with waterproof to prevent rainwater from entering the living space. This can be achieved by adding insulation between the structure and the covering and a possible solution could be elastomeric roofing compound sheets or, in alternative, recycled rubber sheets may serve the same purpose, increasing the recycled content of the whole project.

5.8 Joinery Systems

Although bamboo possesses all the aforementioned advantages and it proves to be a very strong and suitable material for earthquake resistant housing, its connections are not easy to fabricate. Bamboo poles have round and hollow cross sections and are irregularly shaped – mostly tapered – and efficient joinery systems should take into account the material features and wood type connections ought to be avoided.

Also, regardless of the actual joint, all bamboo connections should be analyzed as hinges, unless special devices as knee bracings are provided.

In literature and in construction examples around the world, there are substantially two main types of feasible bamboo connections for Centro Migrante: lashed joints and third-part connections.

Lashed connections

This connection type is the most used way to connect bamboo structures, both for scaffolding and permanent constructions and consists of tying together bamboo poles with lashing or wires. These joints may have problems of maintenance and need to be replaced frequently but they are simple to make and possess inherent stiffness (Hidalgo 2003), (Janssen 1988).

Third-Part Connections (Plug and Bolt)

This type makes use of additional materials to join bamboo poles. Wood or bamboo dowels may be used together with lashing or wires to improve the structural efficiency. Several studies have been published on the topic and the structural integrity of these joint has been tested.

A variation of third-part joints is represented by the use of steel connectors, which further increase the connection strength and durability, in spite of the higher cost. In addition, joints with steel elements are usually coupled with the use of mortar cement, which fills the hollow space in the bamboo pole (Vegesack, Kries et al. 2000), (Janssen 1988), (Villegas 2003), (Gutierrez 2000).

Figure 5-26 Bamboo-steel connection[39]

[39] Joint developed in the wood-metal shop of Renzo Piano Building Workshop – www.rpbw.com

For Centro Migrante housing, the chosen connection type is a combined lashed-thirdpart joint, with the employment of bamboo dowels and wire to join each element of the units. Use of galvanized wire can be considered as well, especially if recycled from other sources. Generally, this joint type offers integrity and efficiency but requires constant monitoring and maintenance, which is the concept embedded in the self-help model.

Exceptions to this connection type are represented by
The foundations: made out of concrete and plastic bottles as tips for the bamboo poles.
The shear wall: the scissor hinge connection is a bolted joint

The following paragraphs offer a series of reference images to explain the connection ideas for Centro Migrante.

5.8.1 Structural connections

5.8.1.1 Beam-Column joint

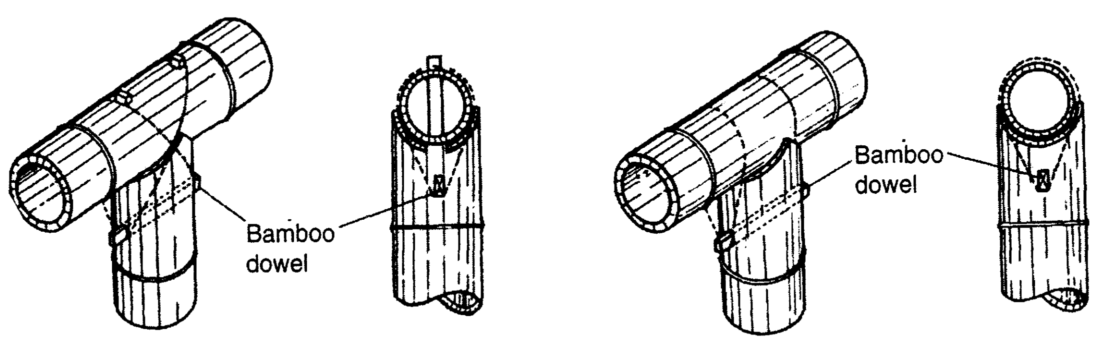


Figure 5-27 Two variations on the dowel-lashing joint[40]

[40] From Hidalgo, O. (2003). Bamboo the gift of the goods.

Figure 5-28 Beam-Column connection with lashing and dowel[41]

[41] Ibid.

5.8.1.2 Raised platform

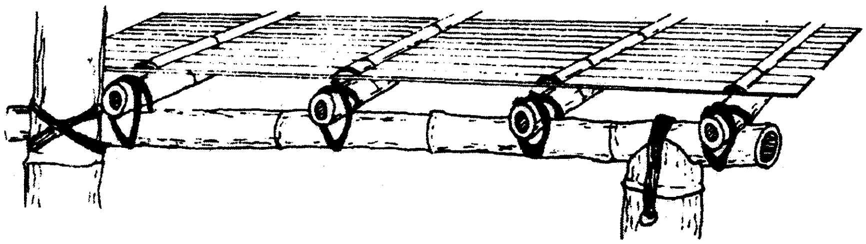


Figure 5-29 Raised Bamboo floor[42]

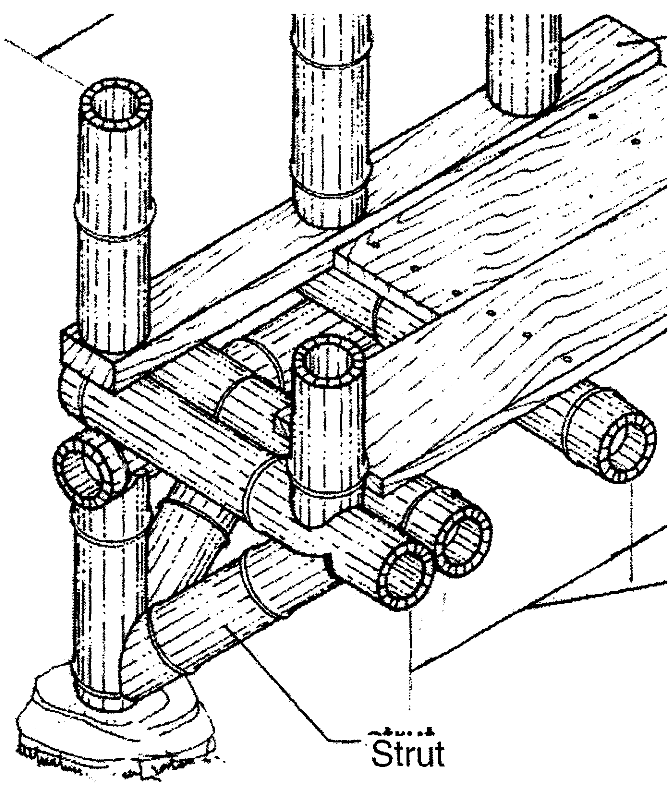


Figure 5-30 Raised Bamboo Platform system[43]

[42] United States. Foreign Agricultural Service. and F. A. McClure (1953). Bamboo as a building material. Washington,, Foreign Agricultural Service.
[43] Hidalgo, O. (2003). Bamboo the gift of the goods.

5.8.1.3 *Roof Trusses*

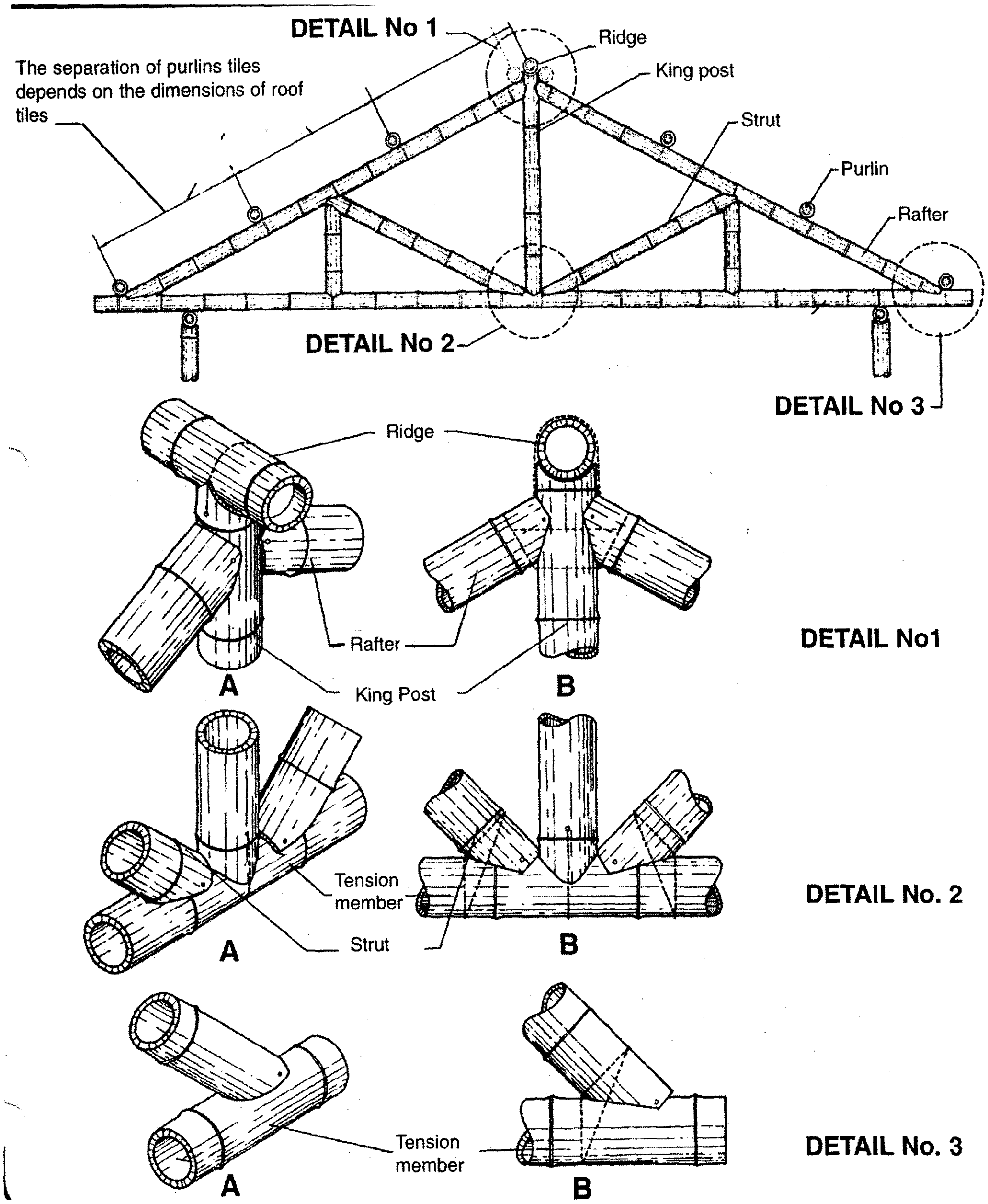


Figure 5-31 Example of Light Roof Truss – system and details[44]

[44] Ibid.

5.8.2 *Non-structural connections*

5.8.2.1 *Roof cover*

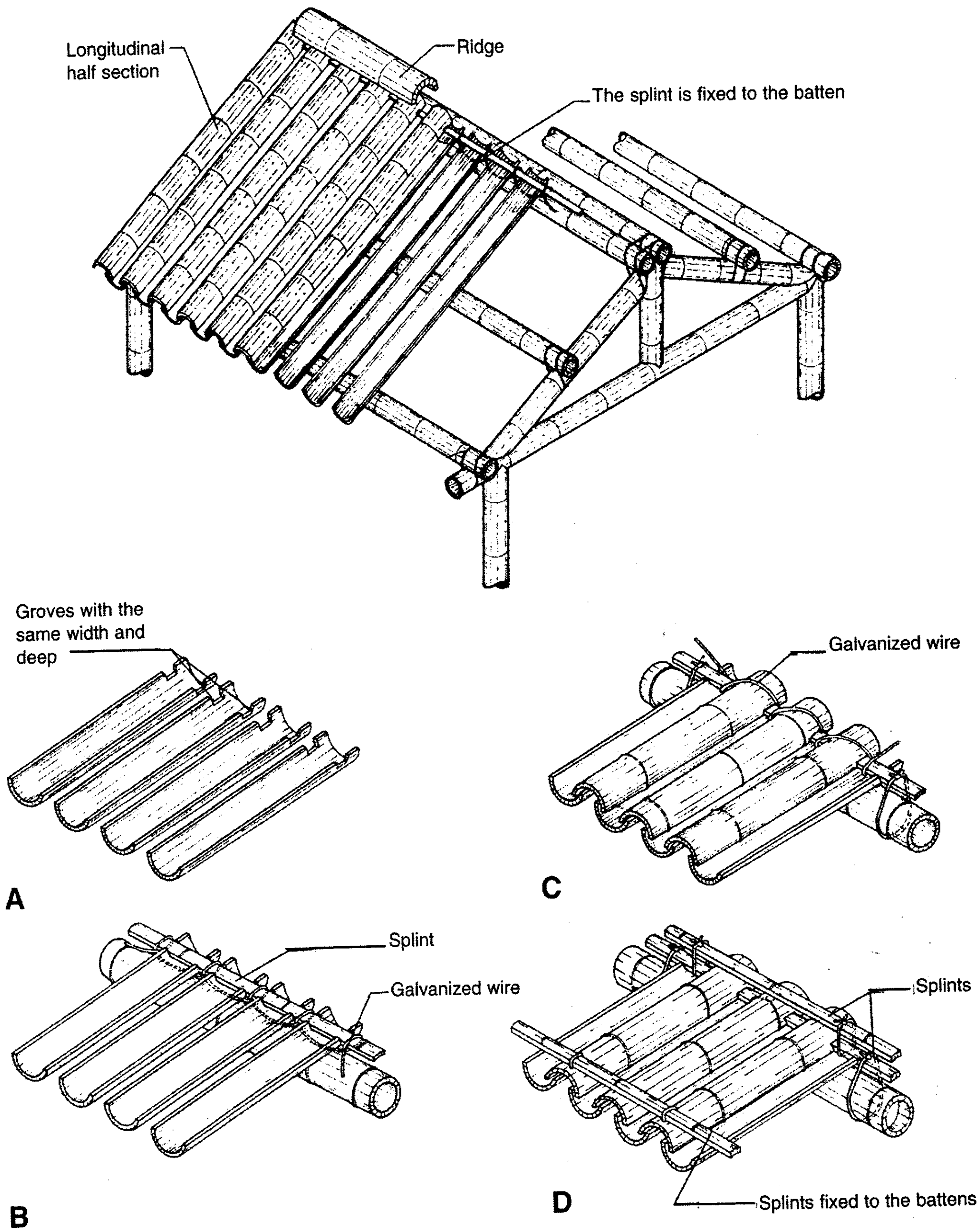


Figure 5-32 Bamboo roof[45]

[45] Ibid.

5.8.2.2 Sawali panel – column joint

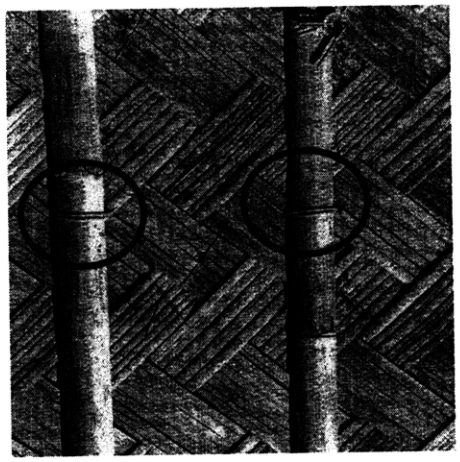


Figure 5-33 Typical Sawali - Bamboo connection with lashing[46]

5.9 *Construction process: assembly – disassembly*

COMPONENT	MATERIAL
Gravity Load Bearing System	Compound Columns and Beams
Lateral Force Resisting System	Bamboo Shear Walls and Knee Bracing
Partition Wall	Sawali (woven bamboo mat)
Roof	Prefabricated bamboo trusses
Floor	Raised Platform
Foundation	Concrete piers and plastic bottles

Preconstruction Issues

Choice of bamboo poles

Bamboo preservation treatment

Off-Site Prefabrication

Roof trusses

Partition walls

---

[46] Ibid.

Shear walls

Knee bracings

Sequence of On Site Mounting

Concrete foundations

Bamboo raised platform

Compound Columns

Shear Walls

Frame Beams

Roof trusses

Sawali partition walls

Capiz shell Windows and Doors

5.9.1 Scissor Hinged Shear Wall disassembly

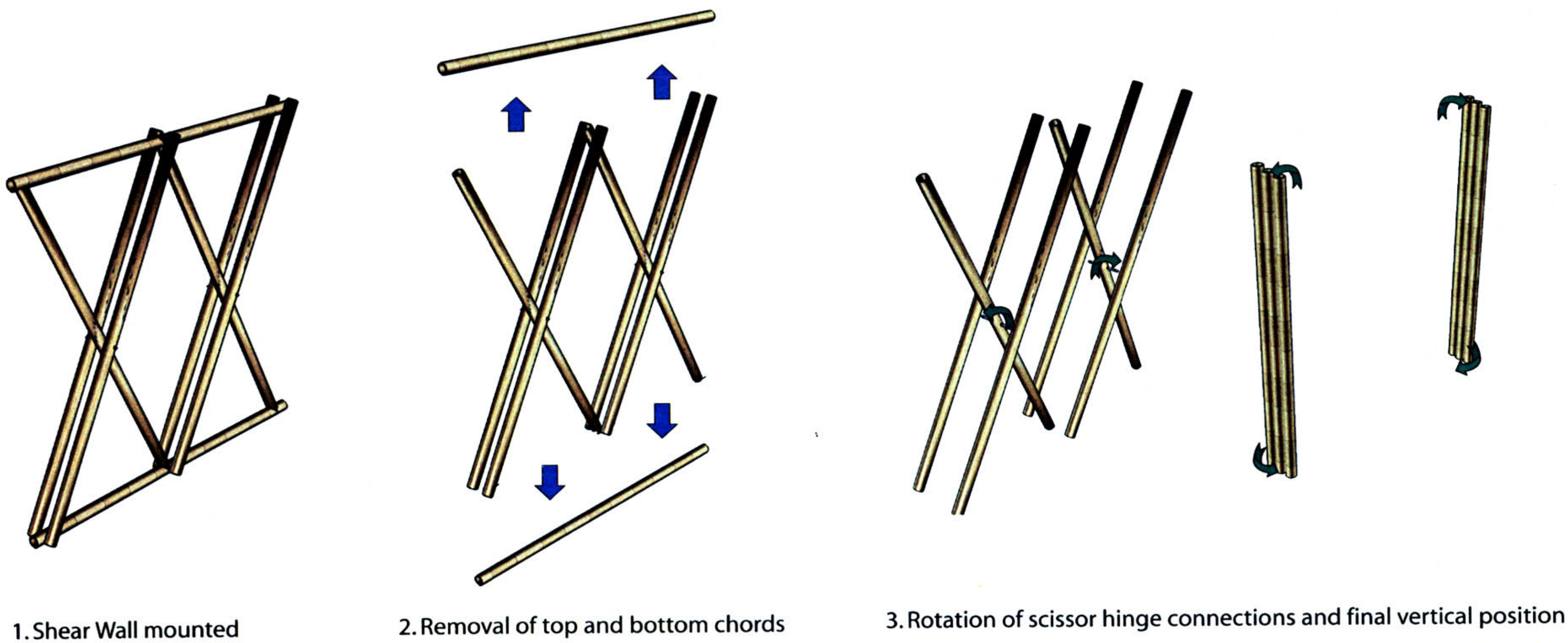


Figure 5-34 Shear wall dismounting sequence

5.10 Alternative Energy Sources & Self-help Model

Given the particular feature of Centro Migrante, the use of renewable energy system in the housing community is complicated to realize. The community is meant to be dismantled and reassembled in a new site every 5 years; therefore, every energy system added to the initial project should take into account a very short payback period, in order to guarantee significant advantages in a short period of time.

In addition, within the low budget of Centro Migrante housing, possible energy alternatives to cut off the center from the electric grid are very few. Possible solutions could be implemented over time, following the self-help concept of the entire community. Once the units will be constructed and each tenant will be involved into the self-maintenance program, new energy programs could be implemented and installed with the joint effort of every community member.

Among the possible options, the following alternatives could be considered, since they can be installed by the tenants.

- SOLAR WATER HEATING

- SOLAR ELECTRIC POWER

- IMPLEMENTATION OF RAINWATER HARVESTING

  With the high-pitched roof solution, rainwater can be collected through special gutters and harvested in containers. The water can then be used for flushing needs in the toilet complex.

CHAPTER VI

6 Preliminary Performance Analysis of the Housing Units

6.1 Calculation of final cost

A preliminary economic analysis has been performed in order to have an estimate of costs for a Single Occupancy Unit. According to Centro Migrante Executive Summary, the cost of one SOU should not exceed 300$ - equal to 13,740 PHP.

Material	Unit C in PHP	Unit Price in $
Bamboo	45 per pole	0.98 per pole
Sawali (Bamboo woven mat)	10 per m^2	0.22 per m^2
Concrete (ready mix 17.5MPa)	3580 per ton	78 per ton
Capiz Shell	40 per m^2	0.88 per m^2
Galvanized Wire (joints)	Recycled content	Recycled content
Plastic bottles (foundation)	Recycled content	Recycled content
Rubber sheets (roof insulation)	Recycled content	Recycled content

Table 6-1 Standardized Unit Price of materials[47]

The following table summarizes the results for the cost of two coupled SOUs in Centro Migrante. As is clear from the values, the cost is low and, although other parameters ought to be considered for a real estimation, the budget constraints set by the Company have been met.

[47] The following prices are a courtesy of Centro Migrante Inc.

Material	Total Cost in PHP	Total Cost Price in $
Foundation	1,180	25.8
Gravity Load System	1,700	37.1
Lateral Load System	1,023	22.3
Roof (structure)	870	19.0
Roof cover and Floor	930	20.3
Walls and Windows	615	13.4
TOTAL	6,318 PHP	**138$**

Table 6-2 Total Cost for two coupled SOUs

6.2 Calculation of embodied energy

Embodied energy refers to energy involved in all the processes associated with the production of a building, from the acquisition of natural resources to product delivery. I It includes the mining and manufacturing of raw materials and equipment, the transport of the materials and the final product fabrication, delivery, use and disposal. Embodied energy is a significant component of the lifecycle impact of a home and it should be estimated to assess the environmental impact of two coupled SOUs.

Material	Unit Embodied Energy	Total Energy
Bamboo	300 MJ/m^3	82 MJ
Sawali (Bamboo woven mat)	400 MJ/m^3	100 MJ
Concrete (ready mix 17.5MPa)	2350 MJ/m^3	212 MJ
Capiz Shell	500 MJ/m^3	80 MJ
Galvanized Wire (recycled)	7 MJ/kg	14 MJ
Plastic bottles (recycled)	80 MJ/kg	150 MJ

Table 6-3 Embodied energy values[48]

[48] [48] The values are a courtesy of Centro Migrante Inc.

The total estimated embodied energy for the project is equal to 638MJ (24 MJ/m^2 including roof area). This value is low, especially if we compare the embodied energy of steel and concrete versus bamboo. More reference data are available in Appendix A.

Conclusions and future work

The results presented in this thesis have been developed in order to offer a design response to the Centro Migrante business plan which is conceived to provide possible solutions to the problem of transient seafarers in Manila. The actual site constraints, including natural hazards and climate, and the multiple design requirements have been analyzed and evaluated in order to formulate an integrated approach for the project. In the Author's opinion, this strategy can be a valuable tool to address the issue of sustainable design in developing countries.

This project does not offer a complete and comprehensive solution, and, in the future, there is need for further work and research to complete Centro Migrante. Detailed site and units layouts should be developed upon visit to the actual site, and precise information on local construction providers and actual costs of materials and construction tools should be acquired. In addition, the site design and urban landscape need to be developed and integrated within the plan for the proposed Single Occupancy Units, contained within the Family Units lot.

In conclusion, the implementation of this research with further work will solution to the need for easy to construct, sustainable, affordable housing.

APPENDIX A: Bamboo properties & diffusion

Bamboo is one of the most interesting products of natural world; its lightness, combined with an exceptional strength and elasticity, makes it an optimal choice as a building material. In addition, its wide availability, especially in developing countries, and low embodied energy are significant factors affecting its overall low cost.

Bamboo has been used as a material in Asia, Africa and South America for many centuries, starting in the II century AD, when it replaced papyrus and parchment.

Throughout the years, it has been used in a wide range of applications, from ceremony objects to furniture to scaffolding for multistory buildings. Nowadays it is being discovered as a versatile building material and architects and designers are currently exploring its possibilities towards local sustainable design projects and technologies.

Bamboo has several inherent advantages: it is inexpensive and locally available in many developing countries locations, it is intensively renewable and possesses a low embodied energy; it can grow faster up to 15 meters in its first year (de Vries 2002). Unlike timber, it regenerates after being harvested (INBAR, 2007) (Hidalgo 2003), (Janssen 1981).

Physical Characteristics of Bamboo

In spite of its appearance, bamboo is not a tree. Bamboo is a grass, fast growing, and typically woody. Its peculiar nature makes it totally different than wood and it is important to understand the nature of the material in order to take full advantage of its properties. The bamboo equivalent of the tree trunk is called "culm" and it is a round-shaped, hollow section tube, organized into a series of internodal cavities divided by diaphragms, which appear on the exterior like nodes. Every bamboo pole may vary in the dimensions of culm height, wall thickness, variation of outer diameter over the pole height (tapered shape), and internodes length. Bamboo is characterized by vascular bundle structure, which gives the material an uncommon tensile and compression strength, significantly larger than wood. For its efficient mechanical properties, bamboo has been named in several sources "vegetable steel", since its fibers possess, on average, a tensile strength of 12,000 kg/cm^2, larger than structural steel.

	Modulus of Elasticity (MN/m^2)	Density (Kg/m^3)
Concrete	25.000	2.400
Steel	210.000	7.800
Timber	11.000	600
Bamboo (average)	20.000	600

Appendix A - Table 1 Mechanical properties of building materials[49]

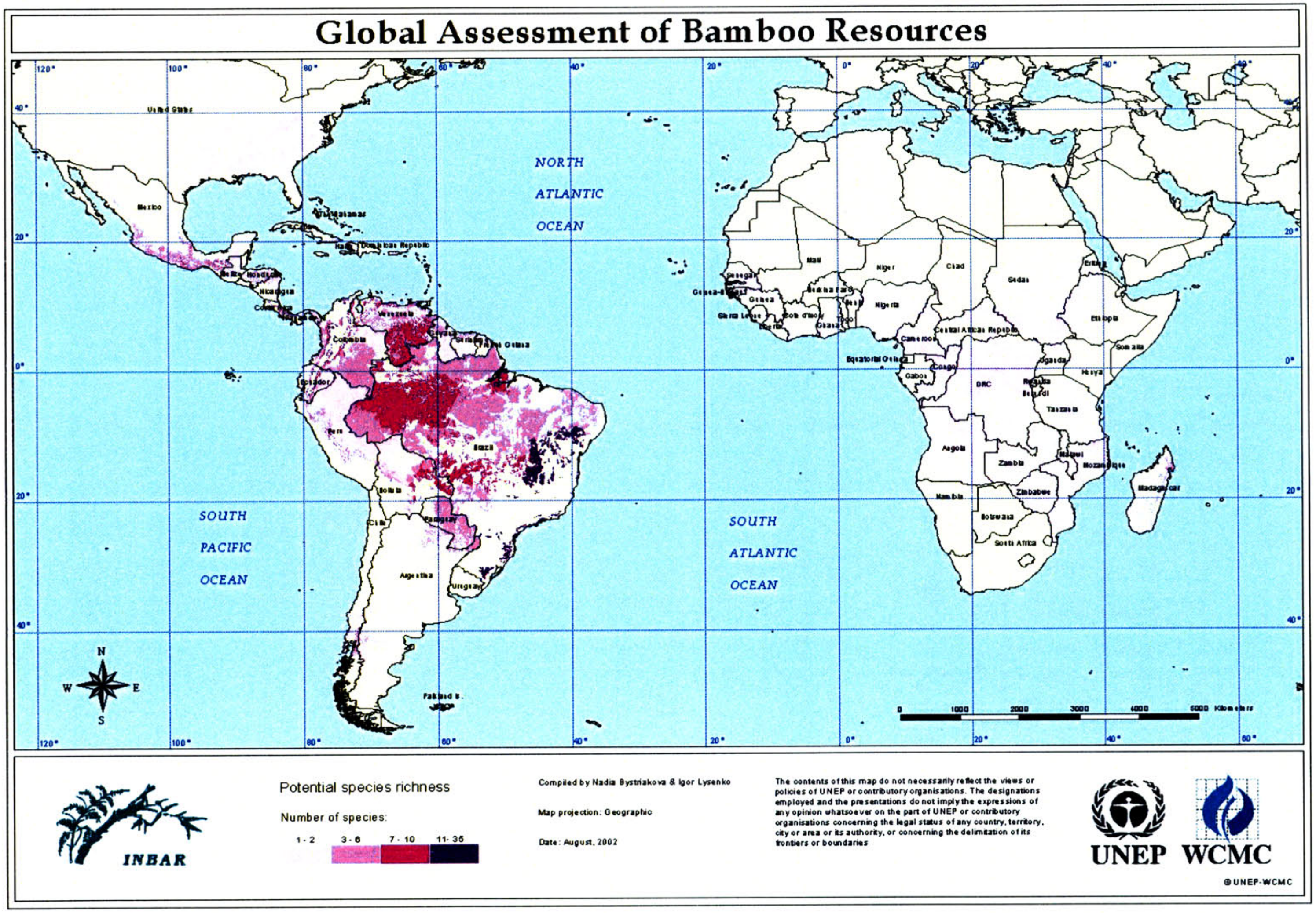
Diffusion

Bamboo is highly diffused in all tropical climate countries, ranging from Central and South America to Asia. More than 600 species are currently known and have been catalogued and, even though the general material characteristics are similar, mechanical and physical properties may vary significantly according to location and species.

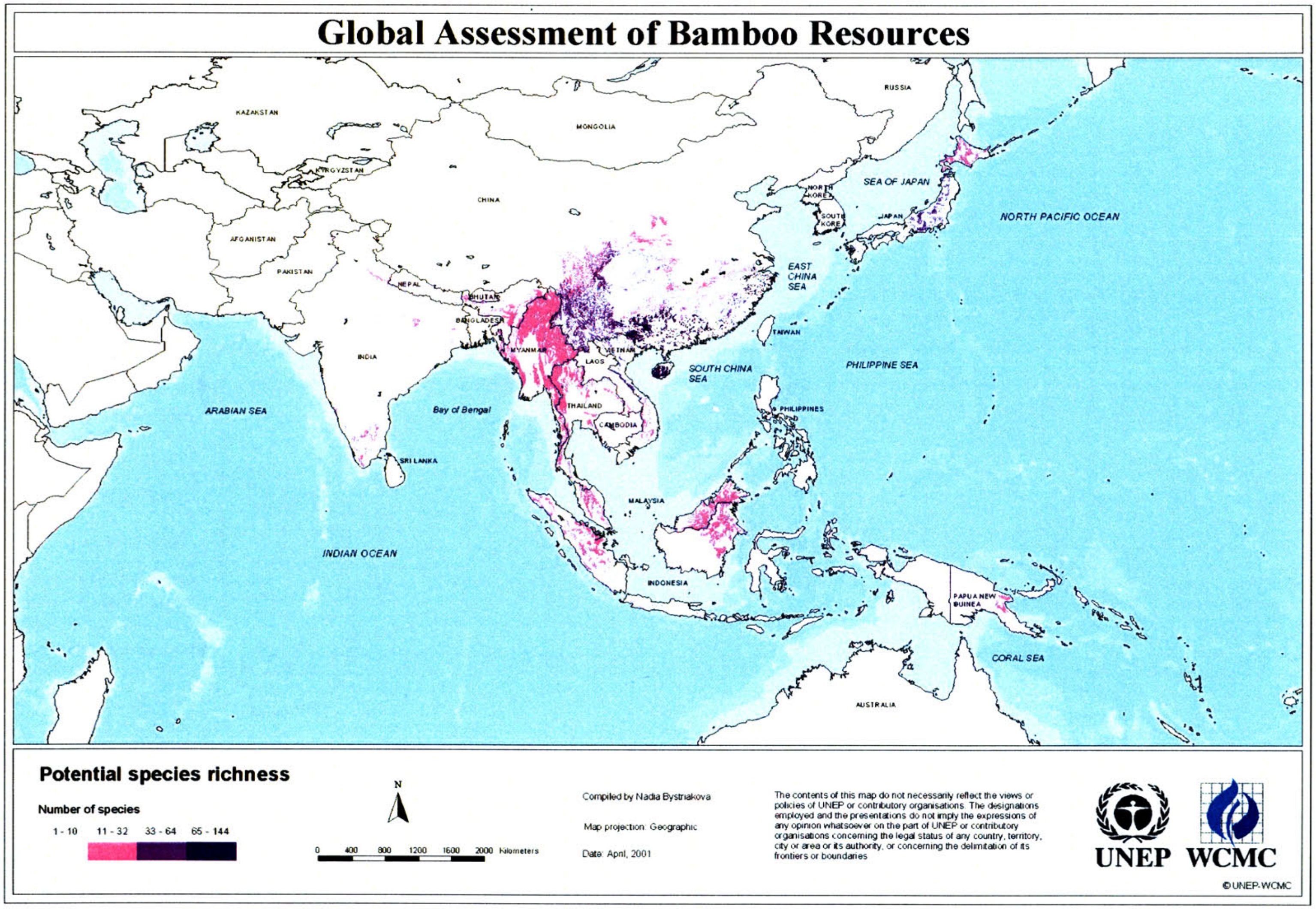
As with steel, concrete, stone and timber, it is important to think of bamboos in terms of distinct and different species, since every plant species possesses specific characteristics, both in terms of strength and dimensions. There are about 1,200 species of bamboo in the world and some of these species can grow to over 30 meters high and have a diameter of 40 to 60 cm, while others cannot reach 7 cm of radius.

One of the most studied bamboo species is the Guadua Angustifolia, a special giant and very efficient bamboo type that grows in South America and widely used in building construction.

[49] Janssen, J. J. A. (2002). "International standard on properties of bamboo." Bamboo for sustainable development. Proceedings of the Vth International Bamboo Congress and the VIth International Bamboo Workshop, San Jose, Costa Rica, 2-6 November 1998: 707-710.



Appendix A - Figure 1 Bamboo diffusion in Africa and America



Appendix A - Figure 2 Bamboo diffusion in Asia

Bamboo in the Philippines

In the Philippines, bamboo is found growing in settled areas where it is planted or grown in plantations and in the forest where it grows from low altitudes to as high as 2,600 meters in the mountain provinces of northern Luzon. One of the most comprehensive sources is the report published from Food and Agriculture Organization (FAO) in 2006[50], which states the existence of 32 bamboo species in the country. According to the report, the commercially important bamboo species in the country are the following:

LOCAL NAME	**SCIENTIFIC NAME**
Kauayan Tinik, or Spiny Bamboo	Bambusa blumeana
Kauayan Killing or Painted Bamboo	Bambusa Vulgaris
Bayog	Dendrocalamus merrillianus
Bolo or Giant Bamboo	Gigantochloa levis
Buho	Schizostachyum lumampao

Among these, the FAO report states that Bambusa Blumeana and Bambusa Vulgaris are the preferred species for building, furniture making and boat outriggers while Bayog is used for tying and making ropes. Bambusa Vulgaris and Bambusa Blumeana can reach a height of 15-20 meters with diameter dimension varying from 6 to 12 cm and wall thickness of 0.7-1.5 cm. In addition, the report contains information regarding the mechanical properties (in psi units) of the two species most used in building construction, although the values reported by Oscar Hidalgo[51] are slightly different.

Species		Tensile Strength	Compressive Strength	Modulus of Rupture	Limit Stress	Young's Modulus
Bambusa	Green		5730	4.119	2930	1.28 10^6
Blumeana	Dry	-	-	-	-	-
Bambusa	Green		5193	9010	6853	1.62 10^6
Vulgaris	Dry		6782	10968	7875	1.70 10^6

Appendix A - Table 2 Philippines Bamboo properties

[50] http://www.fao.org/docrep/X5334e/x5334e09.htm

[51] Refer to Chapter 5 for the values taken from Hidalgo, O. (2003). Bamboo the gift of the goods.

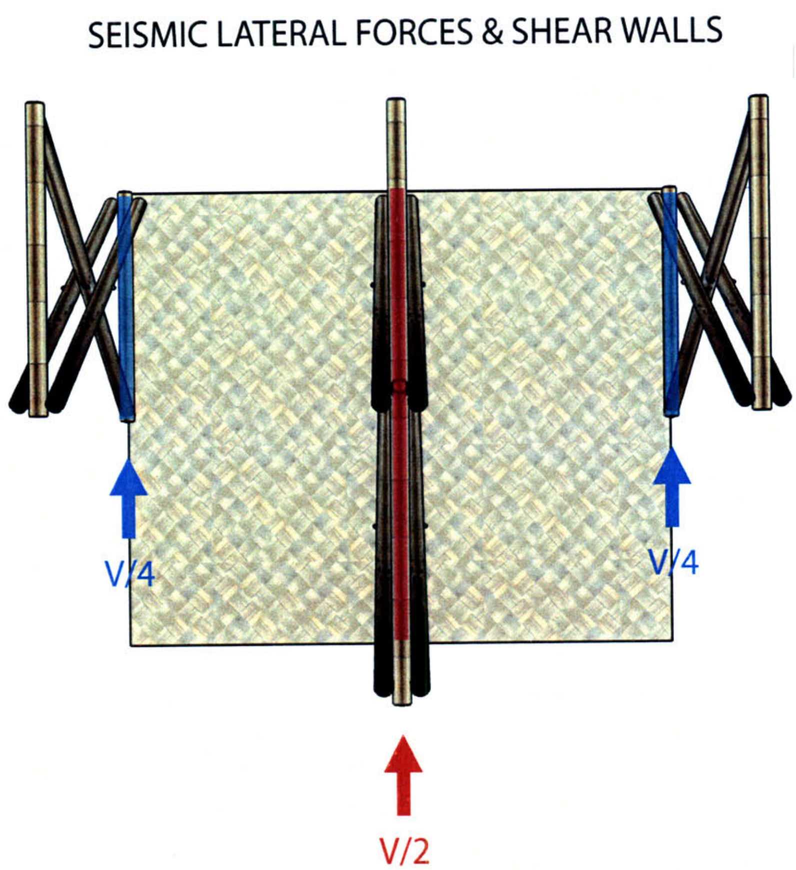
APPENDIX B: Calculation of shear walls

This section contains detailed calculations for sizing the bamboo poles of the shear wall panels. The assumed Modulus of Elasticity for Bambusa Vulgaris is 76205 Kg/m^2.

a) Seismic load and data assumptions

Total base shear for 1-story option = 0.38 W
for 2-story option = 0.24 W

with W[52] = seismic dead load for 2 units



$$V/2 = \begin{cases} 0.19W \\ 0.12W \end{cases}$$

$$V/4 = \begin{cases} 0.095W \\ 0.06W \end{cases}$$

Appendix B - Figure 1 Base Shear Subdivision

[52] In order to take into account loads coming from multiple direction, the value of W includes the actual factored seismic load plus an additional 30%.

$$V^* = 2\gamma h \cdot \left(\frac{AE}{l_d} \right) \cdot \cos^2 \alpha$$

$$A = \left(\frac{V^*}{2\gamma h} \right) \cdot \frac{l_d}{E} \cdot \frac{1}{\cos^2 \alpha}$$

Dimension for the 2-stories options

$$A = \frac{0.12W}{2.6\gamma^*} \frac{3}{0.25} \cdot \frac{1}{E} = 0.544 \frac{W}{\gamma^* E}$$

Dimension for the 1-story options

$$A = \frac{0.19W}{2.6\gamma^*} \frac{3}{0.25} \cdot \frac{1}{E} = 0.877 \frac{W}{\gamma^* E}$$

c) Required Size for Bamboo poles

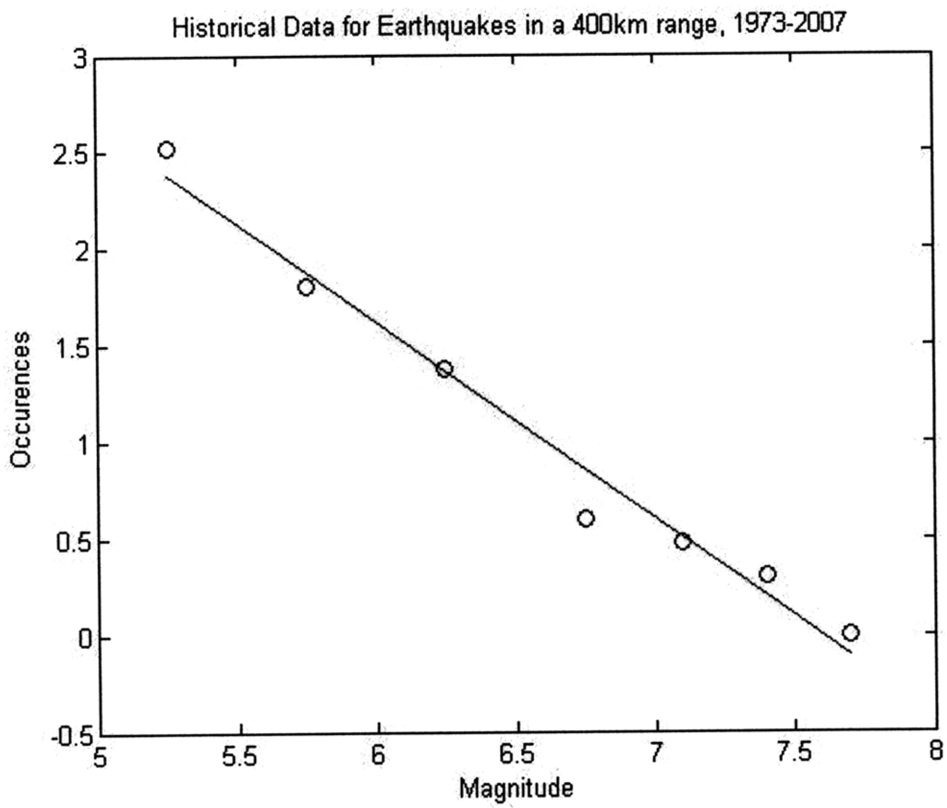
If we assume an interstory drift, γ, equal to 1/200 and a factored (1.2 factor) assumed Seismic Dead load W of 5,781.26 kg for the one-story option and of 8,800.7 kg for the two-story option , the required diameter for the bamboo poles is, in the worst case scenario, equal to 6 cm.

APPENDIX C: Historical seismicity of manila

a) Search performed within 400 km range of the site[54]

Magnitude	Number of earthquakes	Cumulative above lower Magnitude
5.0 - 5.4	334	432
5.5 - 5.9	64	98
6.0 - 6.4	24	34
6.5 - 6.9	4	10
7.0 - 7.4	4	6
7.5-7.9	2	2

Appendix C - Table 1 Number of Earthquakes in 1973-2007



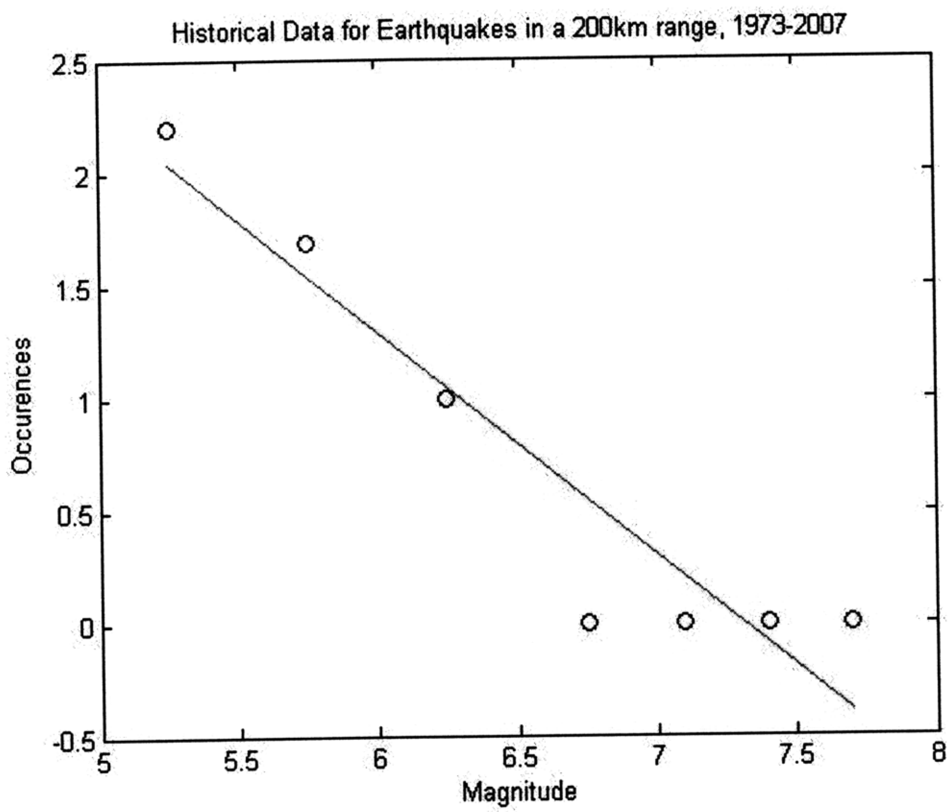
Appendix C - Figure 1 MATLAB plot with data fitted to linear regression

[54] All the data have been taken from the US Geological Service database, www.usgs.gov

b) Search performed within 200 km range of the site[55]

Magnitude	Number of earthquakes	Cumulative above lower Magnitude
5.0 - 5.4	326	1092
5.5 - 5.9	546	766
6.0 - 6.4	157	220
6.5 - 6.9	49	63
7.0 - 7.4	10	14
7.5-7.9	1	4

Appendix C - Table 2 Number of Earthquakes in 1973-2007



Appendix C - Figure 2 MATLAB plot with data fitted to linear regression

[55] All the data have been taken from the US Geological Service database, www.usgs.gov

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