



Architects

Architecture For Disaster Relief

Course Number: AIAPDH259

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Architecture for Disaster Relief Final Exam

1. In a high-wind event, _____ pressures work to pull the parts of the house up.
 - a. Downdraft
 - b. Lateral
 - c. Uplift
 - d. Crosswind
2. In determining the performance of buildings in hurricanes, _____ shapes are best.
 - a. Compact
 - b. Symmetrical
 - c. Simple
 - d. All of the above
3. Prior to European arrival in the Caribbean, most indigenous homes had walls made of _____.
 - a. Adobe
 - b. Wattle and daub
 - c. Brick
 - d. None of the above
4. _____ are classified as either in-ground, above-ground, or within a basement
 - a. Bunkers
 - b. Bomb shelters
 - c. Safe rooms
 - d. Conservatories
5. The two types of flood proofing are _____.
 - a. Up and down
 - b. Wet and dry
 - c. Bitumen and polyurethane
 - d. None of the above
6. The _____ is by far the best shape for earthquake and hurricane resistance.
 - a. Triangle
 - b. Cube
 - c. Dome
 - d. Ellipse

7. When responding to the immediate situation after a disaster it is important that people see _____.
- a. Who is in charge
 - b. Action as soon as possible
 - c. What caused the disaster
 - d. Government involvement
8. _____ is one of the best natural materials for shingle making.
- a. Asphalt
 - b. Rubber
 - c. Birch bark
 - d. None of the above
9. In addition to the obvious physical challenges, there are also _____ needs to be addressed.
- a. Psychological
 - b. Emotional
 - c. Social
 - d. All of the above
10. Some disasters that would have previously been attributed to natural causes, are the result of _____.
- a. Nuclear reactions
 - b. Actions of man
 - c. Meteorological cycles
 - d. None of the above
11. It is important to establish temporary housing in locations that will allow people to _____.
- a. Earn a livelihood
 - b. Be close to ancestral homesites
 - c. Access infrastructures
 - d. All of the above
12. Providing adequate _____ is one of the most intractable problems in international humanitarian response.
- a. Water
 - b. Food
 - c. Healthcare
 - d. Shelter

13. Due to the _____ Fukushima populations had to go to provisional housing further away.
- Destruction of infrastructures
 - Radiation
 - Lack of potable water
 - None of the above
14. Haiti's is one of the _____ countries in the Western Hemisphere.
- Hottest
 - Windiest
 - Poorest
 - Most humid
15. A significant problem with designing and building in Haiti is the lack of available _____.
- Electricity
 - Skilled labor
 - Timber
 - Building inspectors
16. Early examples of man-made buildings were most likely fabricated from _____.
- Wood
 - Bones
 - Hides
 - All of the above
17. In addition to their network of roads, Rome was also famous for their impressive _____ system.
- Aqueduct
 - Welfare
 - Horticultural
 - Agricultural
18. When disaster strikes, _____ is of the essence.
- Planning
 - Time
 - Construction
 - None of the above
19. When providing emergency shelter, materials should be _____.
- Minimal
 - Inexpensive
 - Able to be on site as soon as possible.
 - All of the above

20. The short-term response phase may last _____.

- a. Days
- b. Weeks
- c. Months
- d. Years

21. Many designs for houses after the earthquake of 2010 in Haiti were deliberately designed as _____.

- a. Gazebos
- b. Cabanas
- c. Shacks
- d. Tiny houses

22. Approximately _____ percent of all the energy released in earthquakes comes from the Circum-Pacific Belt.

- a. 20
- b. 40
- c. 60
- d. 80

ARCHITECTURE FOR DISASTER RELIEF

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Architecture for Disaster Relief Course Description/Learning Objectives/Content

Course Description:

This course will investigate the opportunities for architects, designers, and engineers as they address the unique needs and challenges when designing structures and communities in the aftermath of natural disasters.

Course Objectives:

- Objective 1: To gain a basic understanding of the loads that natural forces exert on structures in order to design buildings that provide for the physical safety of the victims of disasters.
- Objective 2: To gain a sensitivity to the mental and emotion need of people for a home, not just a house.

Objective 3: To gain a knowledge of the essential social need of community for victims of disasters and how architects can plan villages to promote a healthy social environment.

Objective 4: To inspire creativity in the approach and design of architectural solutions to protect and encourage people who find themselves in the dire conditions that natural disasters create.

Introduction:

I remember sitting in a studio jury session when I was in architecture school and realizing that most, if not all, of the students were upper middle class or upper class. It wasn't because of the cost of tuition because it was a state university. It was because each individual had grown up with a certain privilege that allowed not having to worry about the rudimentary essentials of life - what one would wear, and what one would eat, and where one would sleep. It was a situation that allowed one to think about "higher" ideas such as the fine arts – painting, sculpture, theatre, and architecture.



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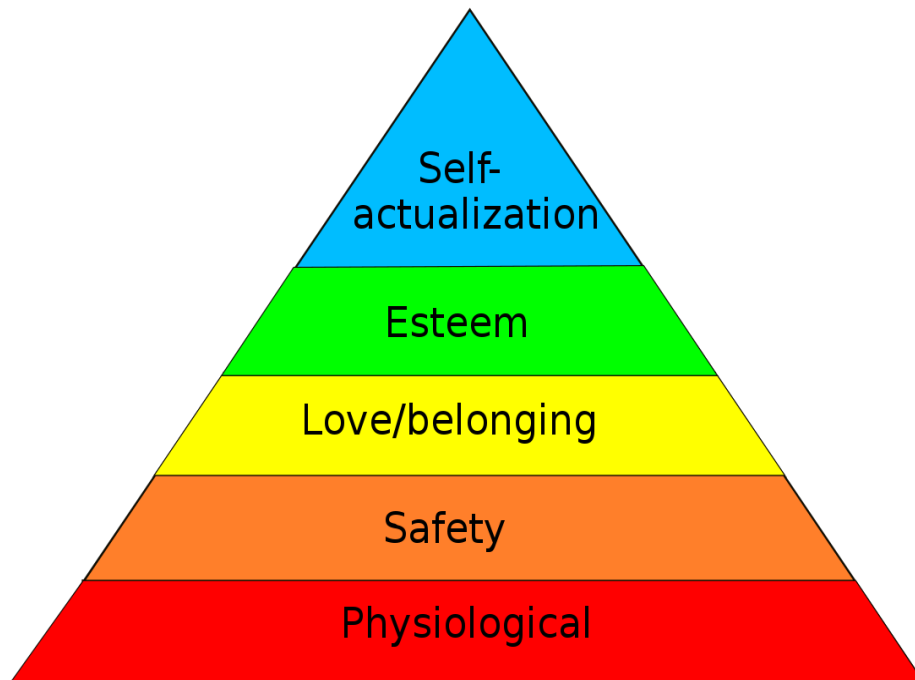
When one thinks of buildings, they think of them as ART. Whereas others who were less privileged only thought of buildings as shelter.



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Abraham Maslow explained the situation with his well-known “Hierarchy of Needs”. Maslow's idea suggests that the most basic level of needs must be met before the individual will effectively desire (or focus motivation upon) the secondary or higher-level needs. Only when our basic foundational needs are met can we ascend to upper levels of human fulfillment and actualization.

Maslow’s Hierarchy of Needs



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For millennia some people have lived and grown accustomed to the “finer things of life.” Even the poor today possess more than the above average person had in years gone by. It is not uncommon to see a homeless person in a third world country with a cell phone. Though life may not be abundant for many in the world today, the vicissitudes of extremity have for the most part been held at bay.

But what happens when catastrophic, life changing events happen? What happens when the society to which we are accustomed collapses? What happens when the shopping malls and light rails and highways and restaurants are all gone? What happens when there are no grocery stores or petrol stations or coffee shops? What happens when there is no available electricity or reliable drinking water or functioning toilets. What happens when the buildings we have admired have collapsed, crushing friends and family?



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Then comes a time when even architects must return to square one and think of buildings primarily as shelter. But addressing the primary need for structure does not preclude addressing of psychological, emotional, and social needs as well, and architects are uniquely qualified to do so.

There are many types of disasters that occur, *force majeure*, some acts of God, some acts of man. In recent times, we recognize that some disasters that would have previously been attributed to God or natural causes, are actually the result of the actions of mankind. It is commonly accepted nowadays that extreme weather events may be due to long term carbon emissions that have been introduced into the atmosphere since the industrial revolution. We still label them as “natural” disasters, but it is a nature that has been influenced, if not abused by mankind, both unwittingly and wittingly. For instance, the perennial wildfires in the western United States have been attributed to the overcontrol of fires that occur from natural causes such as lightning. The Fukushima disaster was a hybrid event, beginning with an earthquake and a tsunami, but ending with a nuclear catastrophe of mankind’s making.

This course will not address the more prodigious disasters of our times such as Chernobyl, or Three Mile Island, not because they are unimportant, but because they are extraordinary. We will instead focus on two of the “ordinary” types of disasters – earthquakes and hurricanes (Atlantic) / typhoons (Pacific).

Though there have been many disasters in recent history, this course will consider only three:

- Indonesian tsunami 2004
- Tohoku earthquake and tsunami 2011
- Haiti earthquake 2010



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Indonesian Tsunami 2004

Tied for 10th place is an apocalyptic magnitude 9.1 earthquake that struck off the west coast of Sumatra, Indonesia, on Dec. 26, 2004. The quake created a catastrophic tsunami that killed approximately 230,000, and displaced nearly 2 million people in 14 South Asian and East African countries. Moving at speeds of 500 mph, the tsunami reached land in 15 to 20 minutes after the quake hit, giving residents little time to flee to higher ground. In some places, the tsunami wave height was over 100 feet high.

Estimated damages from the earthquake and tsunami are estimated at \$10 billion dollars. This event is considered the third largest earthquake in the world since 1900, and its tsunami has killed more people than any other tsunami in recorded history. Because of the time of year, many of the people who died, died because of exposure after the disaster for lack of shelter rather than the tsunami itself. The distance between the beach and the hills in some areas meant that the death toll in some villages was as high as 90%. Twenty days after the tsunami occurred, a medical team found people who had been without food or medical assistance apart from one single air drop. Some children were found on their knees without the strength to stand up.

As is the case in all post disaster programs for housing the victims, there are three stages – emergency shelter, such as tents and lean-tos, temporary or transitional houses, such as barracks and camp cabins, and finally, to normal houses in communities with infrastructures, public spaces, and social/cultural facilities.

In the region of Indonesia where the tsunami struck, there were some pre-existing conditions that were important to consider. Firstly, the people's lives were essentially connected to the pre-disaster ancestral location of their homes. Some of this was due to their livelihoods being dependent on coastal living. Originally, the Indonesian government had forbidden rebuilding on the tsunami devastated areas. At the insistence of many of the survivors, the ban was lifted so that the people could return to where they considered to be their home. Secondly, many of the people had previously been forcibly displaced and placed in military camps built for the refugees of the conflict between the separatist Acehese Freedom Movement and the Indonesian military. This caused them to be frightened by some of the transitional situations from emergency to temporary housing which were often like military styled barracks.

Fortunately, within weeks after the disaster reconstruction was identified as a number one priority for the Indonesian Government and international non-government organizations (INGOs). Within a month of the disaster over 400 international aid organizations had arrived on the scene, with over a quarter of these dedicated to housing reconstruction. Within a period of five years of the disaster more than 125,000 houses had been built in Aceh.

Many of these houses were built from a top-down perspective. They were generally a single plan of minimum standard design established by the BRR (Agency for the Rehabilitation and Reconstruction of Aceh and Nias), which is a 36m² masonry house consisting of one multipurpose room, two bedrooms and one bathroom. Residents had zero input into the design of their house or what their real needs might be.

One development that was originally considered a success was the Indonesia-China Friendship Village usually referred to as the Jackie Chan Village, since the Hong Kong movie star had made a donation to the village and had also visited on one occasion. Originally housing about 2,400 residents that were from several different cultural groups, the population was reduced to half of that in a few years. Even though people liked their new homes, in some cases even better than their pre-tsunami ones, it was just too remote for the residents to find employment. Also lacking were markets, schools, and other amenities needed to successfully support a sustainable community.

Reconstruction in Indonesia after the tsunami is not without real success, however.

The anti-poverty network Uplink Banda Aceh (UBA) maintained that villagers should be able to rebuild where they previously lived. This was at the time when the government had established a "no-build zone." UBA organized protests against the ban and provided temporary shelter and food in coastal villages in the no-build zone. With the help of international funding, they developed resident-driven construction in 23 villages in and around Banda Aceh. They worked

directly with community members to plan and rebuild housing and infrastructure, including community centers and houses of worship.

UBA's philosophy was that "outside parties who want to help disaster victims should empower the communities and consider the role of local institutions, so that community rebuilding post-disaster is initiated by the local people themselves."

By the summer after the tsunami, UBA had salvaged enough wood from the tsunami debris to construct 450 temporary shelters across 23 villages. They subsequently worked with Jakarta architect Marco Kusumawijaya and local community members to plan and build more than 3,000 permanent homes by February 2007. While global organizations were still arguing about processes, UBA had already surveyed villages, obtained local buy-in, and had started building homes. UBA did not limit their role to the construction of housing and infrastructure. They organized community programs and social events. They also helped restore income-generating opportunities. For instance, much of the farmland had been damaged by saltwater, so they taught farmers techniques for enhancing agricultural productivity in high-salinity soil. Those who have studied post-tsunami reconstruction in and around Banda Aceh have discovered that houses built with community participation are in better condition than houses that are built "top-down" by outside developers.

Tohoku Earthquake and Tsunami

The 2011 Tōhoku earthquake and tsunami occurred at 14:46 JST (05:46 UTC) on 11 March. The magnitude 9.0–9.1 earthquake had an epicenter in the Pacific Ocean, 45 miles east of the Oshika Peninsula of the Tōhoku region, and lasted approximately six minutes, causing a tsunami. It is sometimes known in Japan as the "Great earthquake disaster of East Japan", The disaster is often referred to in both Japanese and English as simply "3.11"

It was the most powerful earthquake ever recorded in Japan and the fourth most powerful earthquake in the world since modern record-keeping began in 1900. The earthquake triggered powerful tsunami waves that reached heights of up to 133 feet in Miyako in Tōhoku's Iwate Prefecture, and which, in the Sendai area, traveled at 435 mph and up to 6 miles inland. Residents of Sendai had only eight to ten minutes of warning, and more than a hundred evacuation sites were washed away. The snowfall which accompanied the tsunami, and the freezing temperature greatly hindered the rescue efforts. Ishinomaki, the city with most deaths, was 0°C (32°F) when the tsunami hit. The official figures released in 2021 reported 19,747 deaths, 6,242 injured, and 2,556 people missing, and a report from 2015 indicated 228,863 people were still living away from their home in either temporary housing or due to permanent relocation.

The tsunami caused the Fukushima Daiichi nuclear disaster, primarily the meltdowns of three of its reactors, the discharge of radioactive water in Fukushima and the associated evacuation zones affecting hundreds of thousands of residents. The loss of electrical power halted cooling systems, causing heat to build up. The heat build-up caused the generation of hydrogen gas. Without ventilation, gas accumulated within the reactor containment structures and eventually exploded. Residents within a 12 mile radius of the Fukushima Daiichi Nuclear Power Plant and a 6.2 mile radius of the Fukushima Daini Nuclear Power Plant were evacuated.

Early estimates placed insured losses from the earthquake alone at US\$14.5 to \$34.6 billion. The Bank of Japan offered ¥15 trillion (US\$183 billion) to the banking system on 14 March in an effort to normalize market conditions. The World Bank's estimated economic cost was US\$235 billion, making it the costliest natural disaster in history.

The Need for Shelter

One of the most pressing consequences of disaster is that a large number of houses are destroyed or rendered uninhabitable, and a large number of people are left without a safe place to live. As a part of disaster management, shelter-after-disaster management attempts to respond to this need during the emergency phase and afterwards during recovery work. In the Humanitarian Emergency Response Review, Paddy Lord Ashdown states that "Providing adequate shelter is one of the most intractable problems in international humanitarian response."

Temporary Housing

Temporary or emergency *shelter* focuses on providing shelter for the period immediately after the catastrophe. The purpose of temporary *housing* is to support victims during the recovery period allowing victims to begin return to their normal domestic life and daily routines. When people lose their houses they also lose their privacy, their identity, and their apparent dignity as human beings. Temporary housing is intended to provide a space for protection, privacy, and dignity. Temporary

housing is also intended to enable family and community life, creating a sense of normalcy in the lives of the affected people.

Industrialized Temporary Housing

To address the immediate demand for a large quantity of temporary housing units, industrial construction materials and methods would seem to be “go to” solutions. While such solutions will suffice for a period of time, the dangers of decontextualization leading to dehumanization are very real and this type of temporary housing will soon become counterproductive in the quest for normalization.

Temporary Housing in Japan

The post-disaster shelter management model in Japan is distributed along three stages or phases:

- Emergency shelter for *immediate* response
Used for days, weeks, or at most months
- Provisional housing for *short term* response
Use is variable, from one to five or six years
- Permanent housing for *long term* response
Either a return to status quo architecture or new more appropriate designs

Design

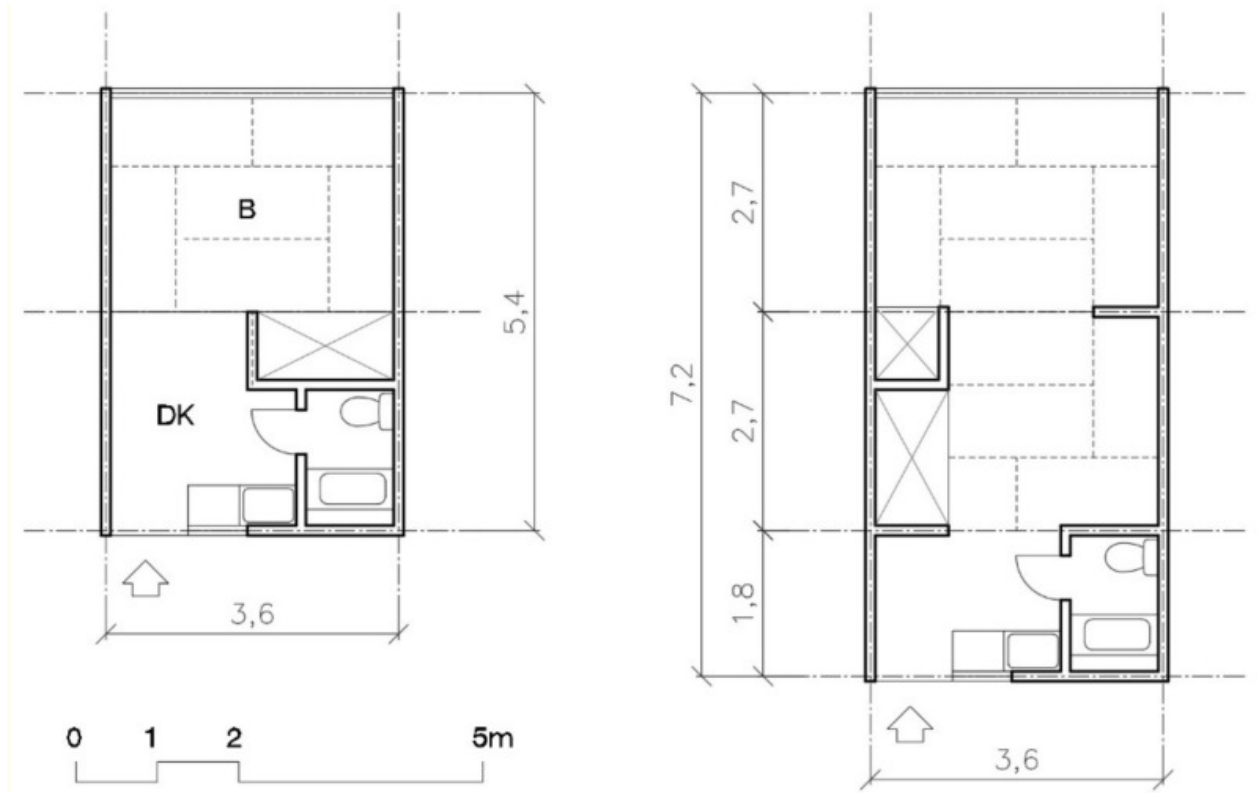
The Japanese temporary housing has followed a single design with very little variation in the last 25 years. The design promotes the social isolation of residents, making recovery from the psychological, emotional, and social problems that obtain after a disaster very difficult.

Efforts were made to improve the social health of residents by moving pre-disaster communities together to the same camp and place temporary housing areas as close as possible to the residents’ original neighborhoods. This proved to be of some help, but it was not possible to set up camps in some of the areas of the destroyed neighborhoods.

The architecture and design of the temporary housing areas proved not to be a solution but rather a part of the problem.

Japan’s temporary houses used light metallic-structure prefab, over which elevated flooring made of plywood sheets was placed 12 inches above the ground. The ceiling and walls were composed of thin wooden sheets plated by thin galvanized steel. There was no thermal insulation or any type of noise cancellation.

Two models were offered: one bedroom with 215 ft² and two bedrooms with 280 ft². The houses were equipped with a prefabricated bathroom and a small kitchen. The rooms were sized using tatami mats ~ (3ft × 6ft), which determined the size of the room: ~ 9ft X ~12ft.



Most of the temporary housing areas could hold 250 to 1000 temporary houses, although some were much more populated, including one camp that had more than 2000 houses. The matrix layout of the houses, all facing the same direction, meant that entry doorways never faced each other and reduced the possibilities of interaction between neighbors. Also, there were no allowances for plazas, courtyards, or any kind of public space. The overall scheme was more that of a concentration camp.

Tōhoku 2011 continued...

The extent of the disaster's area, and the specific location of the affected areas due to the radioactive contamination from Fukushima, resulted in different ways in how the temporary housing areas could be managed.

More than 50,000 temporary houses had to be manufactured. Houses were similar to what has been described, however at Tohoku, wooden manufacturing companies built more than 6000 units, 4000 of which for Fukushima. It took approximately two months to manufacture the prefab housing, and the wooden houses a bit more. However, it took several more months for many of the temporary housing areas to become available. In September 2018 seven and a half years after the earthquake, there were still more than 5600 people living in temporary housing areas in Iwate, Miyagi, and Fukushima.

In Tōhoku, it was not possible to locate temporary housing areas near the areas where people formerly lived. Due to the radiation around Fukushima populations had to go to provisional housing further away. Also, in the areas affected by the tsunami it was hard to find suitable

land to set up the temporary housing areas, so those affected had to move to areas further away from their original houses.

At least one community center was built for every fifty temporary housing areas to organize activities to improve and encourage relationships between residents. Centers to care for the elderly were also included in some temporary housing areas.

Special initiatives were initiated in the temporary housing areas like the “Do it Yourself” and “Home for All” projects. The “Do it Yourself” project was a collaboration between two private companies, the Royal Home Center Co. Ltd. and Daiwa House Industry. The project provided materials and know-how so residents could improve their houses by building additional features such as benches, awnings, and fences. The “Home for All” project is an initiative of the architect Toyo Ito. The project’s main mission is to enable residents to participate in the construction of centers for meetings and celebrations as a community-building strategy.

Because of the huge number of temporary houses that needed to be built and the tight deadlines for assembly, the building quality was very low resulting in complaints from the residents. Some common complaints were the lack of ventilation under the floor, which resulted in mildew, condensation on windows, the oppressive heat in the summer due to insufficient insulation and the lack of privacy because there were no sound deadening measures.

In Tōhoku, in addition to the more industrial metal/wood houses, three prefectures built temporary wooden houses. There was a large variety of types which made for a more human sense of place. The wooden houses were preferred by the residents. They took longer to build but the price was similar to that of the metal/wood prefab houses.

It is disturbing that though many of the problems that obtained after the earthquake/tsunami were architectural in nature, very little was actually contributed by architects to solving the problems. Rather temporary housing units and their arrangement in camps remained *status quo* even though there were decades of evidence that the approach was not only not working but was in many ways compounding the problems.

Japanese temporary housing units have barely changed in the 25 years since. The houses were intentionally designed to provide autonomous and self-sufficient life inside of it. This would seem to be right thinking providing safety and privacy. But self-sufficiency can be isolating and counterproductive to social health. M.A. Smith compared China and Japan’s post-disaster temporary housing areas. The Chinese units differed from the Japanese in that the Chinese units were not autonomous. The Chinese units were simply bedrooms with no running water. All bathing and dining were done in common facilities necessitating daily contact with others in the community increasing socialization and improving the psychological and emotional health of the residents.

Kodokushi, or “lonely death” means death alone without the care or company of another person. In Tōhoku 230 cases of *kodokushi* were recorded in six years (2011 to 2016), according to the National Police Agency, 97 were in the first three years. In contrast to the 230 cases of *kodokushi* in the Japanese camps, the Chinese had no cases at all.

Not only have there been no architectural improvements to the temporary housing units, but there have also been no urban design improvements either. The matrix layout of the houses, all facing the same direction, meant entry doorways never faced each other and reduced the possibilities of interaction between neighbors. No public spaces were designed into the camps. This is indicative of the prevailing ideology of design that is based on physical production and not human needs.

There is the saying that “a house is not a home,” and the adage is key to the misunderstanding that supplying a house is enough to solve the needs of disaster victims. What the victims have lost is not just their houses, but their homes, which includes all their belongings, which provided them with their identity as well as the loss of family members and friends. After a disaster, the relationships that the affected people had with friends, neighbors, and acquaintances in their communities are broken.

Certainly, a physical structure is a major part of restoring what has been lost, but the psychological, emotional, and social aspects of community life are the essential elements of what will successfully provide the victims with new *homes*.

The philosopher Takashi Uchiyama criticized the Japanese government’s management of the Tōhoku disaster. According to Uchiyama, recovery is neither revival economy, nor rebuilding houses, but the rebuilding of relationships between people and between human beings and nature. For architects that means designing villages not just houses. Villages with houses arranged in schemes that will encourage social exchange with neighbors. Villages that will include plazas and parks and marketplaces.

A good starting place for rebuilding community would be public forums, where the members of the [new] community could contribute their ideas and the expression of their needs could be heard. Granted that during the extreme and chaotic times immediately following a disaster, it is difficult to congregate people in any deliberate and organized way, but it is important that the affected people feel that they are part of the solution to the enormous problem they find themselves in. If they feel like they are helpless and at the mercy of the government, NGOs, and charity organizations, rather like children who cannot help themselves, then they will become depressed and lose vision for a future restoration and a return to normal life.



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Haiti earthquake 2010

A catastrophic magnitude 7.0 earthquake struck Haiti just northwest of Port-au-Prince on Jan. 12, 2010. It ranks as one of the three deadliest quakes of all time. Haiti is one of the poorest countries in the Western Hemisphere. It's limited experience with large earthquakes left Haiti extremely vulnerable to destruction and loss of life. As many as 3 million people were affected by the quake. Death toll estimates range from 230,000 to 316,000 persons.

The earthquake impacted a country whose buildings were not built to any regular engineering standards. Pierre Fouche, at the time, Haiti's only earthquake engineer, said he was saddened by the fact that so many who died were killed because buildings in Haiti were so poorly constructed. Haiti does not have a national building code. Most people in Haiti still live and work in unreinforced buildings, typically constructed of brick, block or concrete. Such buildings are considered to be rigid and lack any of the ductility that is required to be resistant to the kinds of forces of earthquakes exert.

Early promises of building a new Haiti by programs such as those inaugurated by former U.S. Secretary of State Hillary Clinton were supposed to be symbols of the new nation, but the failures of these endeavors only highlighted the intractable housing problem of Haiti. A mere fraction of the permanent houses promised for Haiti have been built, and the quality of the materials used in the homes have been deemed so inferior that USAID officials say they are considering taking legal action against contractors. The Haitian government financed a development called Lumane Casimir Village on the outskirts of Port-au-Prince. Two years after

it was started, only 30 percent of the development was completed, and just 477 of 1,280 of the completed homes were occupied.

In a Miami Herald interview., USAID Mission Director John Groarke said that the enormous housing problem Haiti faced could not be resolved just by having donors build houses. Rather he believes the focus should be helping Haitians build their own house as well as assisting the Haitian government in building their own roads and infrastructure. This has become a recurrent conclusion after many failed attempts at top-down solutions to disaster relief around the world.

Post-Earthquake Haitian Architecture

A significant problem with designing and building in Haiti is the lack of available timber. This is due to the mass harvesting of trees in the past to produce charcoal. Consequently, current Haitian architecture continues to rely on concrete to build dwellings and other buildings. Most of the concrete used is in the form of blocks which are often combined with traditional stonework. Roofs are generally composed of locally sourced palm thatch. Unfortunately, the roofs are prone to hurricane damage and the walls are vulnerable to earthquake damage. A great challenge lies in designing and building structures and dwellings that will survive future natural disasters, while being affordable to a nation with such a weak economy.

Review Questions

1. The American psychologist who created the Hierarchy of Needs was _____.
 - a. Abraham Lincoln
 - b. Sigmond Freud
 - c. Abraham Maslow
 - d. Carl Jung
2. Fukushima was a hybrid disaster with an earthquake, _____, and a nuclear meltdown.
 - a. Cyclone
 - b. Tsunami
 - c. Typhoon
 - d. Tornado
3. Many of the people who died in the Indonesian tsunami of 2004, died because of _____.
 - a. Starvation
 - b. Dehydration
 - c. Drowning
 - d. Exposure
4. The three responses after a disaster are _____, short term, and long term.
 - a. Immediate
 - b. Longevity
 - c. Brief
 - d. Overall

5. After a disaster people prefer to rebuild _____.
- A different location
 - On higher ground
 - The place where they lived before the disaster
 - Near an escape route
6. Successful reconstruction is usually done by _____.
- Experts
 - General contractors
 - NGOs
 - The victims themselves
7. The Japanese word for “lonely death” is _____.
- Hari kari
 - Kamikaze
 - Kodokushi
 - Sudoku
8. The greatest loss people suffer from disasters is their _____.
- House
 - Belongings
 - Home
 - Employment

EFFECTS OF DISASTERS

STRUCTURAL DAMAGE

- RESIDENTIAL

There is abundant evidence that ancient humans found shelter in natural formations such as caves and tree hollows, but there is also evidence that early humans also built structures to protect themselves from the natural elements as well as from predators. Some of the earliest examples of man-made buildings were most likely fabricated from wood, animal bones and hides and consequently have not survived. Some current primitive and nomadic societies live in huts and tents that may be very similar to these earliest human architectural endeavors. Mongolian yurts or Native American tepees and wigwams are examples.

Not unlike other animal species, humans are familial and structures that humans have built are primarily residential, shelters to protect themselves from exposure to the elements as well as safe places to eat, sleep, work, and play without fear of predation whether from wild animals or other people.

In addition to supplying the lower level of Maslowian needs of safety and security, residences also provide people with opportunity to express their personalities and sense of aesthetic and pride.

When disasters destroy peoples' residences, they are bereft of their most important physical means of protection and dignity.

STRUCTURAL DAMAGE

- PUBLIC

In addition to being familial, humans are also social, congregating and living in close proximity to other families. Both opportunities and problems arise when people live together, and social contracts must be made. These contracts help protect individual freedoms, but also seek to take advantage of human association resulting in laws, commercial enterprises, and public institutions which are beneficial to the individual because they are beneficial to the whole.

Consequently, just as the familial aspects of human life gave rise to residential building, social aspects of human life gave rise to commercial and public buildings - commercial buildings for shops and offices and public buildings for public administration and law enforcement.

When disasters destroy our social and public buildings, order suddenly becomes chaos.

INFRASTRUCTURE DAMAGE

- TRANSPORTATION
 - ROADS
 - BRIDGES
 - RAILS
 - SHIPPING PORTS
 - AIRPORTS

In addition to the residential, commercial, and public buildings that humans built, pathways to move themselves, their livestock, and their goods from one place to another were also developed. Herd paths became trails, which became roads which connected intra-community buildings and highways that connected nearby villages, towns, and cities. Plank roads, stone pavements, and even concrete roads became important infrastructure for human activities. The ancient Roman road system was very sophisticated even by today's standards. The Romans standardized the width of their roads to 4.2 meters (4.6 yards) wide to allow for two-way traffic. They also built their roads with a slight slope to allow water run-off. At the peak of the Roman Empire, over 50,000 miles of highway made it possible to effectively rule the ancient world. Modern interstate and state highways along with bridges, railways, shipping, and airports are essential for the movement of people and goods and the velocity of the economy.

When disasters destroy the arteries of commerce and supply, life essentials are cut off and society risks collapse.

INFRASTRUCTURE DAMAGE

- UTILITIES
 - ELECTRICAL
 - WATER
 - COMMUNICATIONS

In addition to their vast network of roads, Rome was also famous for their impressive aqueduct system bringing needed water from miles away to their citizens for drinking and irrigation.

Modern infrastructures now include more than roads, railways, shipping channels, and airports. Just as important are networks of pipes and wires that distribute water, gas, electricity, and data.

When disasters destroy infrastructures, essential lifelines are severed.

TIMELINE

When disaster strikes, time seems to come to a standstill but actually time becomes of the essence like never before. After a disaster, there are three essential timely responses – immediate, short term and long term.

Disaster.....Immediate response.....Short term response.....Long term response

IMMEDIATE RESPONSE

Immediately following a disaster, a rapid response is crucial. Medical services are required for bodily injuries, as well as immediate attention to damaged structures to insure some level of safety and security. Often casualties due to exposure after the disaster exceed those caused by the actual disaster event. This was certainly the case with 9.1 earthquake and ensuing tsunami that struck off the west coast of Sumatra, Indonesia, in the middle of winter on Dec. 26, 2004.

Well-intentioned but ill-advised responses like what happened in Haiti after the 2010 earthquake seemed to provide for the immediate need for shelter but were actually recipes for further disaster by erecting windsails and providing potential wooden projectiles.



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Not only were the structures themselves potentially dangerous, but they were also arranged like chicken coops without any regard for the sociological needs of the people. Supplying the more basic Maslowian needs does not preclude considering the higher needs of people. Architects are uniquely capable of designing solutions to immediate physical needs of people while recognizing the mental, psychological, emotional, and sociological needs as well.

When responding to the immediate situation after a disaster event, it is important that people see action as soon as possible, both for physical protection and safety and for emotional encouragement. Promises with procrastination and inaction cause the people to be discouraged and to distrust those who are trying to help.

Materials should be minimal, inexpensive, and able to be on site as soon as possible. If possible, construction methods should be kept simple, so that the victims of the disaster can perform most, if not all, of the actual construction.

One effective tactic to shelter people from the elements immediately after a disaster event is the employment of survival shelters using natural materials such as tree limbs, branches, and leaves in forested areas. In areas where there are no trees dugouts can be made into the earth. In areas where there is significant snow fall, the snow can be used to build igloos.

SHORT TERM RESPONSE

After the immediate needs are met, an intermediate or short-term response should be planned and executed. This would include both temporary structures as well as a rudimentary community planning including roads, activity specific zoning, and infrastructure easements. The short-term response phase may last for years and should be a large advance forward toward a more permanent and normal build out. It need not be a “familiar” architecture, since the architecture that was familiar is what failed in the disaster event. Social life will not have returned to normal yet, so the community arrangement may still be more of a camp than a village, but if many of the needs of the population are being successfully met, the people will be encouraged and will afford patience toward the next phase of the recovery of normal life.

LONG TERM RESPONSE

Long term response would include analysis and evaluation of historical and traditional building materials and methods as well as consideration of contemporary and futuristic materials and

methods. The traditional buildings and infrastructure that have been destroyed may provide a nostalgic desire to return to the past but advances in new materials and methods should not be ignored, since a prime objective for future development will be to prevent or at least to protect as much as possible from a similar disaster.

Architects are also prone to succumbing to trying to recapture the past. Many designs for housing after the earthquake of 2010 in Haiti were deliberately designed as shacks. The argument was that this was the architectural vernacular to which Haitians were accustomed and their culture should be respected. The fault with that argument is that Haitians were not living in shacks by cultural choice, but because of their poverty.

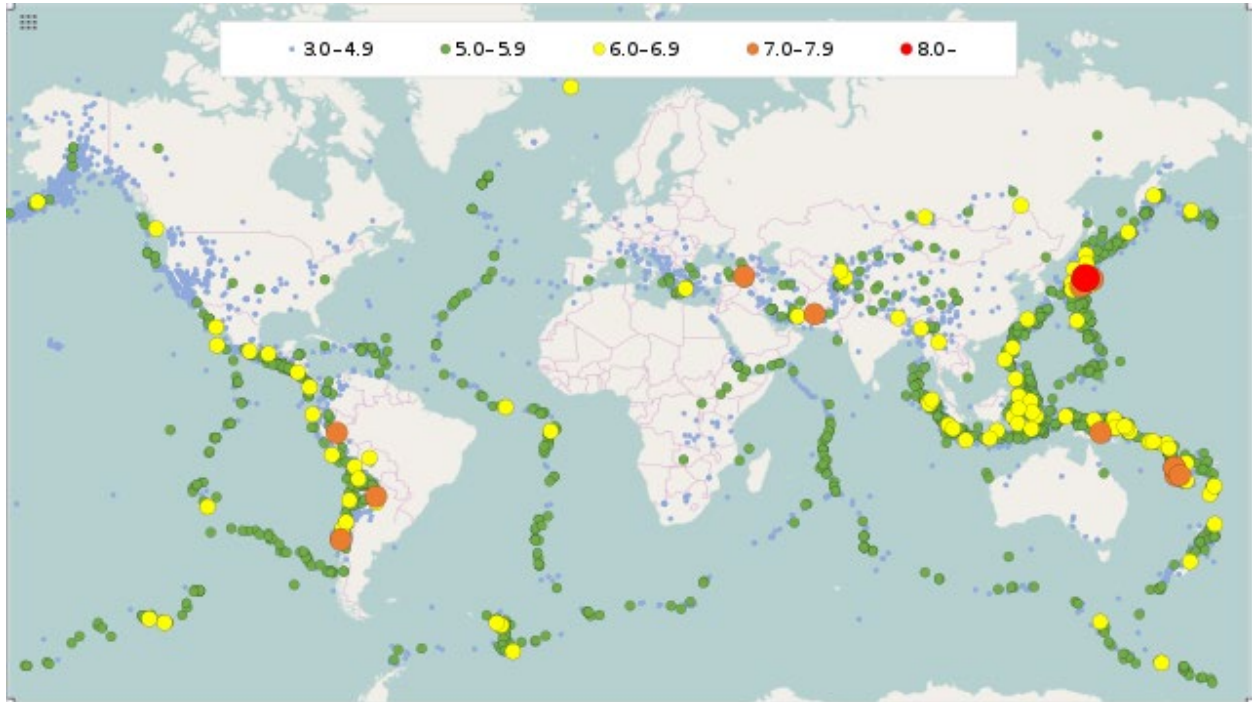
The devastation from the earthquake actually afforded an opportunity to start anew with buildings that would be more appropriate to the conditions of the country. Just as high sloped roofs are common in northern Europe to shed snow and stucco and large overhangs are common to sunny areas in the south, Haitian buildings need to be designed considering the frequent earthquakes and powerful hurricanes that continually plague the country.

Earthquakes

Causes of Earthquakes

The causes of earthquakes are numerous, including underground explosions, movement of magma within volcanoes, and impacts of large objects with the ground. These types of earthquakes usually have low intensity and rarely cause significant damage. However when earthquakes occur because of sudden movements that occur within the earth's crust they can be very dangerous and cause great damage. The earth's crust has a series of large cracks that divide it into a series of very large plates, called tectonic plates. Gravitational forces, forces induced by the earth's rotation, and forces generated by convection within the earth's molten core cause these tectonic plates to be shoved against each other, causing stress and strain energy to build up within each plate and along the boundaries between these plates. These tectonic earthquakes are explained by the so-called elastic rebound theory, formulated by the American geologist Harry Fielding Reid after the San Andreas Fault ruptured in 1906, generating the great San Francisco earthquake. According to the theory, over a period of years, the stresses will accumulate to a point where they exceed the frictional resistance between the plates or the strength of the rocks. When this happens, sudden fracturing results and a rapid shift of the earth's crust will occur, releasing some of the strain energy that has been stored over the years. This energy is released in the form of kinetic energy that radiates outward from the zone where the differential movement occurred. This causes the ground shaking and other geological effects associated with earthquakes.

Locations of Earthquakes



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An earthquake can occur anywhere, but most earthquakes occur along lines of weakness in the earth's crust, which are termed faults. Faults can often be found along the bases of mountain ranges and hills that were formed by past tectonic activity on these faults. The most important earthquake belt is the Circum-Pacific Belt. It affects many highly populated coastal areas around the Pacific Ocean. Approximately 80 percent of all the energy released in earthquakes comes from this belt. Because at many places the Circum-Pacific Belt is associated with volcanic activity, it has been often referred to as the "Pacific Ring of Fire", but there does not appear to be a direct causal link between volcanoes and earthquakes. They are probably only related due to the activity of the same tectonic processes. A second belt, known as the Alpide Belt, passes through the Mediterranean eastward through Asia and joins up with the Circum-Pacific Belt in the East Indies. The energy released in earthquakes from this belt is about 15 percent of the world's total.

Size of Earthquakes

Earthquakes are measured by quantifying the size and severity of an earthquake, respectively termed magnitude and intensity. Magnitude is a measure of the amount of energy released by an earthquake event. C. F. Richter measured magnitude on the basis of how much a standard seismic wave measuring instrument deflected, when located a specified distance from the place where an earthquake occurred. Richter created a logarithmic magnitude scale ranging from 0, for earthquakes that release negligible energy, to 9 or more, for the largest earthquakes that have ever occurred. An increase of 1 unit on the Richter scale represents an increase by approximately 32 times the amount of energy released, so that, a magnitude 6 earthquake releases approximately 32 times more energy than a magnitude 5 earthquake, and a magnitude 7 earthquake releases approximately 1,000 times more energy than a magnitude 5 earthquake.

Tsunamis after Earthquakes

Tsunami is a Japanese word for “harbor wave”. Following some earthquakes, long-wavelength water waves in oceans or seas sweep inshore. They sometimes come ashore at great heights above mean tide level. Such waves can be extremely destructive. The usual cause of a tsunami is sudden displacement in a seabed sufficient to cause the sudden raising or lowering of a large body of water. The most destructive tsunami ever recorded occurred on December 26, 2004, after an earthquake displaced the seabed off the coast of Sumatra, Indonesia. More than 200,000 people were killed by a series of waves that flooded coasts from Indonesia to Sri Lanka.

Review Questions

9. Ancient humans found shelter in _____.
 - a. Caves
 - b. Hollows of trees
 - c. Huts
 - d. All of the above

10. In addition to being familial, humans are also _____.
 - a. Psychological
 - b. Social
 - c. Emotional
 - d. Competitive

11. The Romans standardized the width of their roads for _____.
 - a. Live stock
 - b. Chariots
 - c. Aqueducts
 - d. Two way traffic

12. Often short term housing solutions are like _____.
 - a. Villages
 - b. Camps
 - c. Towns
 - d. Cities

13. The earth’s crust is divided into a series of very large plates, called _____ plates.
 - a. Tectonic
 - b. Dental
 - c. Geological
 - d. Geographical

14. Most earthquakes occur along lines of weakness in the earth’s crust, which are termed _____.
 - a. Cracks
 - b. Fissures

- c. Faults
 - d. Crevasses
15. The Circum-Pacific Belt is often referred to _____.
- a. Circle of Death
 - b. Pacific Ring of Fire
 - c. Volcano Row
 - d. Pacific Triangle
16. An increase of 1 unit on the Richter scale represents an increase by approximately ___ times.
- a. 2
 - b. 4
 - c. 16
 - d. 32
17. *Tsunami* is a Japanese word for “_____”.
- a. Sushi
 - b. Earth shake
 - c. Harbor wave
 - d. Coastal storm

Earthquake resistance building design

The vertical movement of the earth caused by earthquakes is not responsible for the greatest damage to buildings since all structures are designed to withstand vertical forces, i.e. the force of gravity. It is the rolling horizontal waves of an earthquake that exert the extreme and damaging horizontal forces on structures. These forces cause lateral accelerations. Lateral accelerations are measured as G-forces. A sudden movement to the side creates enormous stresses for a building's structural elements, including beams, columns, roofs, walls, and floors, as well as the connectors that hold these structural elements together. When those stresses are great enough, the building can collapse or suffer extreme damage.

Shape

When designing building in seismic areas, it is best to avoid irregular or asymmetrical designs, such as “L” or “T” shaped buildings or split-level structures which are more susceptible to torsion (twisting along longitudinal axes). Keeping buildings symmetrical allows seismic forces to be distributed equally throughout the structure. Limiting cantilevers, decorative elements or anything easily dislodged from a building is also advised.

Foundation

By definition, when an earthquake occurs, the earth “quakes” or moves. It is, therefore, necessary to isolate the foundation from the earth to prevent seismic waves from traveling through a building. This is referred to as “base isolation”. There are several strategies to accomplish this.

In typical perimeter wall foundations, instead of using rigid concrete footings, some flexible support should be used. These can be rubber pads or some other shock absorbing material that will vibrate during the shock of the earthquake but will prevent the seismic activity from engaging the building itself allowing it to remain steady. If the building can be saved from experiencing seismic oscillation, structural failure can be prevented.

Another solution involves floating a building above its foundation on a system of bearings, springs or padded cylinders. Engineers often choose lead-rubber bearings, which contain a solid lead core wrapped in alternating layers of rubber and steel. The lead core makes the bearing stiff and strong in the vertical direction, while the rubber and steel bands make the bearing flexible in the horizontal direction. Bearings attach to the building and foundation via steel plates and then, when an earthquake hits, allow the foundation to move without moving the structure above it. As a result, the building's horizontal acceleration is reduced and suffers far less deformation and damage.

Monolithic slab on grade is also an effective seismic resistance foundation. The structure must be effectively attached to the slab. According to the International Residential Code (IRC), anchor bolts should be at least ½-inch diameter and should be embedded at least 7 inches into the foundation concrete. They should be spaced no more than 6 feet apart. Any wall section over 24 inches long should have at least two bolts, located at least 3.5 inches but no more than 12 inches from the ends of the sill plate. Every bolt should have a tightened nut and washer.

Materials and Earthquakes

Steel

It is commonly thought that steel buildings do not do well under the stresses of earthquakes, when in fact, steel buildings have advantages over concrete buildings in earthquakes.

Common sense makes us think that the heavier and more rigid an object is, the stronger it is. We assume that the weight of concrete would help hold a building down, and the stiffness of concrete would resist the swaying under the wind impact. That would be true for loads that are solely lateral, but an earthquake is different than other loads. The earth itself moves, laterally and vertically moving the foundation of the building and the forces involved are of such a magnitude that the weight of the building is inconsequential. In fact, like judo, a building's weight actually works against the structure. The greater the mass of a building being put into motion, the greater the force exerted on the structural elements, and on the connections between those structural elements. A lighter structure undergoes less damaging force because it has less mass – and therefore less force – to damage itself under seismic shaking.

It is especially important for taller buildings, to be made of light and flexible materials such as steel that can flex with the movements that earthquakes create. Multi-story buildings that are fabricated with steel are 60 to 70 percent lighter and 10 times stronger than buildings that are made of concrete of the same size. Because of these attributes, buildings constructed primarily from steel require less earthquake proofing than those made with other materials.

For a building material to resist stress and vibration, it must have high ductility — the ability to undergo large deformations and tension. Buildings that are constructed primarily of steel or other metals are highly ductile and therefore are much better at resisting earthquakes. Steel is much lighter than concrete and more flexible than concrete and other building materials, making it more likely to bend instead of break when experiencing seismic force.

According to the World Steel Association, buildings that are ductile are much safer than stiffer buildings as they dissipate energy from seismic waves. A building will typically have ductile parts that can undergo plastic deformations without complete structural failure during an earthquake

Wood

Wood is the most widely used construction material in the United States, particularly for residential buildings. Census data show that, nationwide, out of 14,000 multi-family buildings completed in 2015, more than 87% were wood frame. Of 648,000 single-family houses completed that year, more than 93% were wood frame. And in the earthquake-prone Western United States, roughly 98% of all existing homes—from modest dwellings to luxurious mansions—are wood frame structures

The aftermath of historical earthquakes around the world has repeatedly proven that wood frame buildings generally perform well during earthquakes. One example is the so-called Gingerbread Houses, a distinctly Haitian architecture which originated in the late-19th century with the Haitian National Palace. It is a style that was inspired by Parisian architecture, although modified for the Caribbean climate and to local cultural aesthetics. Gingerbread Houses were usually built of wood and masonry or stone and clay and had wraparound balconies and featured steep turret roofs which were used to redirect hot air. They were usually designed with louvered shutter windows to take advantage of the breezes and flexible timber frames to withstand earth tremors and storms. Only around 5% of Gingerbread Houses were destroyed or damaged during the 2010 earthquake (compared to around 40% of other structures). These facts have left experts thinking that they could serve as a model for future seismic-resistant architecture.

Review Questions

18. When designing building in seismic areas, it is best to avoid _____.
- a. Irregular plans
 - b. Asymmetrical designs
 - c. Split level structures
 - d. All of the above
19. To protect from earthquakes, it is necessary to _____ the foundation from the earth.
- a. Integrate
 - b. Isolate
 - c. Elevate

- d. Levitate
20. A lighter structure undergoes _____ damaging force than a heavier one.
- More
 - Less
 - Equal
 - None of the above
21. For a building material to resist stress and vibration, it must have high _____.
- Resilience
 - Compression
 - Ductility
 - Rigidity
22. _____ is the most widely used construction material in the United States.
- Concrete
 - Steel
 - Aluminum
 - Wood
23. A Haitian architecture which originated in the late-19th century is the _____ house.
- Painted lady
 - Gingerbread
 - Victorian
 - Hurricane

Wood-frame buildings can be designed to stand up to high winds and earthquakes given the following characteristics:

• **Inherent Flexibility**

Wood's ability to withstand high loads for short periods of time and retain its elasticity and ultimate strength can be an asset in seismic and high-wind zones.

• **Lightweight**

Forces in an earthquake are proportional to the weight of a structure. Wood-frame buildings typically weigh less than those made of concrete and steel, which are typically seven times as heavy, reducing inertial seismic forces.

• **Ductile Connections**

The ability to yield and displace without fracturing under abrupt lateral or horizontal stresses is an attribute of wood-frame construction, which features typically nailed connections that allow it to respond to seismic and high-wind events without critical failure.

- **Redundant Load Paths**

Wood-frame construction provides numerous load paths through shear walls and diaphragms, which typically have hundreds of structural elements and thousands of nail connections. The numerous fasteners and connectors used in wood-frame construction offer multiple, often redundant, load paths for extreme forces, reducing the chance the structure will collapse if some connections fail as opposed to structures built with heavy frames constructed from non-wood materials having relatively few structural members and connections. The failure of one load path can lead to overloading of adjacent members or joints.

- **Connectivity**

The connection of structural elements to the foundation is essential. Wood-frame construction is easy to secure to the foundation using standard connections and tie-downs manufactured for high-load designs.

- **Strength and Stiffness**

The thickness of mass timber panels and the number and size of nails fastening the assemblies determine each component's stiffness. Heavy bracing for shear walls can resist lateral distortion common in earthquakes. The lateral forces of an earthquake tend to rack (trapezoid) buildings. Shear walls provide racking resistance, and walls and diaphragms (roofs and floors) constructed with panels of plywood or oriented strand board (OSB) over lumber framing have proven to be effective. Strength and stiffness of structural elements is increased by using thicker structural panels and on both sides if necessary and increasing the number of fasteners.

- **Design and Engineering**

The 1994 Northridge Earthquake was a milestone for engineering of wood structures. Most of the structures badly damaged in Loma Prieta earthquake of 1989 were built prior to "modern" codes, however the Northridge earthquake caused damage to structures even though they were built in the era of updated codes. Wood light-frame construction was a significant part of the overall poor structural performance in the Northridge Earthquake. A significant number of people died in the collapses of wood light-frame structures. More than 200 apartment buildings were heavily damaged. In the Reseda area of the San Fernando Valley, some entire neighborhoods were turned into ghost towns as many apartment buildings were condemned and could not be occupied.

Some buildings had weak/soft stories which explained their failures, but some recently constructed multi-family residential buildings with engineered shear wall systems that appeared to conform to recent building code provisions also failed. This led to a revisitation of accepted engineered design and detailing practices.

Historically, wood frame structures have not generally benefited from engineering design because wood construction practices had not been codified uniformly across the country until the 1990s. Seismic design specifications for engineered concrete and steel buildings have been standard for some time, but seismic design provisions for wood frame construction have been less specific.

While the first code addressing the construction of wood frame construction was published in the early 1970s, it was not mandatory nor was it enforced by local building departments. After

the Northridge earthquake, a new awareness of wood frame vulnerability initiated subsequent editions of building codes and construction standards for wood frame construction to become mandatory in many jurisdictions throughout the US.

In 2000, the first International Residential Code (IRC) was published by the International Code Council (ICC), the organization that publishes the International Building Code (IBC). The IRC was developed with the specific intention of overseeing the design and construction of detached one- and two-family dwellings and townhouses, as well as other residential occupancies (including dormitories and apartments of fewer than three stories). The IRC was adopted by many state and local governments, and by the end of 2002 the 2000 version of the IRC was adopted by most states. By 2017, the IRC had been adopted by 49 states and the District of Columbia.

Since the adoption of the IRC, building quality has improved dramatically which can be attributed to improved codes and standards resulting in better design, especially with new hold-down systems to resist overturning, and specially manufactured hardware to better control load paths. An anomaly that exists, however, was that in many cases, wood frame buildings constructed in the 1940s and 1950s performed better than those built in the 1960s. Even though the houses were built with inferior practices in the 1940s all the way to 1970s, the houses were built with simpler geometries in both plan and elevation, were smaller in size, had smaller rooms, and had smaller and fewer window and door openings in the exterior walls. All of these factors provide the majority of the lateral support for wood frame buildings. Contemporary architectural features which became popular in the 1960s led to designing homes with fewer solid exterior and fewer interior partition walls. This alone resulted in a significant reduction in the lateral load-carrying capacity of these homes.

In addition to the more “open plan” preferences, many multi-story wood frame buildings are weakened by the “soft story” in which the structural stiffness or strength is much lower on the first floor than other floors because of large openings (such as garage doors or open floor plans), while upper floors have more partitioned rooms. In addition, seismic demand is driven by the combined effects of the frequency content of ground motion and the natural period of buildings. The spectral acceleration experienced by a one-story wood frame building is lower than that of a two-story building during an earthquake. This results in lower seismic forces and reduced damage in one-story buildings.

Basic Design Theory for Wood Framed Structures - Diaphragms and Shear Walls

Engineered systems are designed to resist earthquake loads. A lateral load path is established, and each element is designed to resist the calculated earthquake force. Roofs and floors are designed as diaphragms and some of the walls are designed to function as shear walls. Diaphragms and shear walls are used to transfer loads and to keep the building from distorting or twisting. Designs require adequate sizing of lumber framing elements and connections between all of the framing elements in the load path. Connections are especially important as this is where most failures occur. Nails and framing anchors are required to connect the diaphragms to shear walls. Hold-down connections are used to hold down the corners of the shear walls and anchor bolts are required to connect shear walls to the foundation.

Traditional Light-framed Wood Construction

Most wood construction in the U.S. is currently still light-framed wood systems, and has been like since the mid-1900s. Light-frame construction is a system of construction using many small and closely spaced members that can be assembled by nailing. It is the standard for U.S. housing. Early forms of light-frame construction were balloon-frame houses with wood cladding *Balloon framing*, sometimes called Chicago framing, is a system of framing in which the vertical elements of the exterior walls, i.e. studs, extend the full height of the structure from the soleplate to the roof plate. Floor joists are fastened to the studs either by being nailed or screwed to the sides of the studs or by sitting on a ledger that has been let into the studs. The name comes from the French *maison en boulin*, *boulin* being a French term for a horizontal scaffolding support. Invented in Chicago in the 1840s, Balloon framing aided the rapid settlement of the western U.S. Balloon framing was replaced by another form of light-frame construction, *platform framing*. In platform framing, each floor is framed separately and sits on the story beneath it, as contrasted with balloon framing, in which the studs extend the full height of the building from sole plate to the rafters. Platform framing offers an easier and safer system of construction. Carpenters fabricate each story floor, which is supported by the story beneath it. The floor serves as the working platform on which the stud wall frames are fabricated in sections and then lifted into place. On top of this is placed a second floor or the roof. The roof is formed of rafters (sloping joists) or wood trusses.

Light-frame building consists of dimensional lumber framing and wood panel sheathing, which performs very well in earthquakes from a life-safety standpoint for two main reasons:

- as a natural material, wood is much lighter than steel and concrete and has intrinsic flexibility, making it more resilient to earthquake loading
- the redundancy in light-framed wood building load paths makes it very robust against collapse. Even when most structural components are heavily damaged, the building system can still manage to remain standing by developing alternative load paths.

Major research and engineering projects have made strides in improving light-framed wood building seismic performances, including:

- CUREE-Caltech Wood Frame Project (1995 - 2000) supported by FEMA after the 1994 Northridge Earthquake in California. This was the first systematic investigation into seismic performance of as-built light-framed residential buildings. Wood shear walls were tested in the lab, effects of non-structural finishing materials were assessed, numerical models were developed for earthquake response prediction and large-scale shake table tests on full wood building structures were conducted. The project established a foundation for quantitative understanding of wood building response in earthquakes.
- NEESWood Project (2005 - 2009) supported by the National Science Foundation. This project took learnings from the CUREE project and pushed it to a higher level. The objective was to develop performance-based seismic design methods for mid-rise wood buildings that are not only safe but also have reduced damage during large earthquakes. A direct displacement design (DDD) method was proposed and verified using a full-scale six-story light-framed wood building on the E-Defense shake table in Japan. The project

attracted great attention because it was the world's largest building tested on a shake table to date.

- NEESSoft Project (2010 - 2013) supported by the National Science Foundation. The NEESSoft project examined *existing* wood building retrofit opportunities, focusing on "soft-story buildings". Soft-stories are ones that have large openings on the first floor. A full-scale four-story apartment building was tested to the point of collapse at the end of the project. Effective retrofit techniques were developed in this project and verified in full-scale testing before the collapse.

By 2014, earthquake engineering for light-framed wood buildings developed to a point that:

- multi-story wood buildings up to six stories could be constructed to withstand large earthquakes with limited damage.
- existing soft-story buildings could be retrofitted to withstand large earthquakes without collapse
- a comprehensive set of design and analysis tools for light-framed wood building had been developed and validated through large shake table tests.

Although the size and height limit of wood construction is still limited in the International Code Council's (ICC) International Building Code (IBC), light-frame wood building design has made it possible for wood buildings with the seismic performance levels of typical steel and concrete systems for mid-rise construction.

Review Questions

24. Wood-frame construction provides numerous _____ paths through shear walls and diaphragms.

- a. Load
- b. Critical
- c. Extreme
- d. Resistance

25. The 1994 _____ Earthquake was a milestone for engineering of wood structures.

- a. San Francisco
- b. Tacoma
- c. Northridge
- d. San Andreas

26. In 2000, the first International _____ Code was published by the International Code Council.

- a. Building
- b. Administrative
- c. Electrical
- d. Residential

27. Soft-stories have _____.

- a. Large doors
- b. Garage doors
- c. Large windows
- d. All of the above

28. Diaphragms and shear walls are used to transfer _____.

- a. Forces
- b. Loads
- c. Frames
- d. Vibrations

29. _____ construction is a system of construction using many small and closely spaced members.

- a. Braced framing
- b. Heavy framing
- c. Arkansas framing
- d. Light framing

30. Balloon framing is sometimes called _____ framing.

- a. New York
- b. Boston
- c. Chicago
- d. Denver

Mass Timber and Tall Wood

Wood is a surprising ductile material due to its high strength relative to its lightweight structure. Timber already has a good reputation in earthquake-prone regions. Wooden structures often survive and, being strong and light, tend not to collapse heavily and crush their inhabitants in the manner of poorly built concrete homes. This is the reason why traditional housing in San Francisco area is built from wood. Timber is very strong, but it is also very brittle when it fails so ductility for deformation capacity must be supplied by other means. This is usually accomplished using steel rods and brackets. The downside to this is that after an earthquake the rods and brackets must be replaced. One solution is to allow the walls to rock or slide. This is called a rocking wall. The walls are made from cross-laminated timber (CLT) and designed with post-tensioned cables. With this design, the building's core rocks and then re-centers itself in the event of an earthquake while sustaining little to no damage to the primary structure, avoiding any need to demolish the building after an earthquake and making it more easily repaired.

A full-scale validation of new CLT wood building components was completed at the world's largest outdoor shake table, at the University of California San Diego. Katerra, a construction company investing heavily in cross-laminated timber (CLT) construction material, saw its seismic shear wall tested. Katerra's wall system was tested at three different intensities -- medium, large, and extreme. The wall system achieves its seismic resistance through rocking mechanisms placed along the base of each CLT panel, allowing the building to absorb energy and flex horizontally under load.

The results showed that:

- Under medium intensity the system experienced no damage
- Under large and extreme intensity, damage occurred, but only at the connection devices

The CLT performed as well as steel or concrete. However, in the event of an earthquake, Katerra's wall system allows the damaged connection devices on the building to be pulled out and easily replaced. This would not be possible with steel or concrete.

Michael Green is a Canadian architect and an author of books on mass timber construction. *The Case for Tall Wood Buildings* is a case study on using materials such as cross-laminated timber (CLT) panels and engineered glulam wood beams to build skyscrapers as tall as 30 stories. In 2013, Green gave a TED talk titled "Why we should build Wooden Skyscrapers". Green's architecture firm Michael Green Architecture designed the seven-story T3 building in Minneapolis, which was built using 3,600 cubic meters of wood, and is intended to sequester about 3,200 tons of carbon for the life of the building.

Cross Laminated Timber (CLT) is an innovative wood product invented in Europe in the 1990s. CLT consists of 3 to 11 wood layers glued together to form solid panels with a thickness normally ranging from 60 to 320 millimeters (2.36 – 12.6 inches). The great benefit of the material is in its intrinsic sustainability, the rapid building process, and great flexibility of use. CLT has been used primarily for low-rise residential, commercial, mixed-use buildings, but recently architects are beginning to propose buildings made in CLT with 6 stories and over, such as the nine-story Stadthaus Building in London and the 10-story Forte Building in Australia. These projects have demonstrated through testing that wood components with large volume (mass timber) can survive fire for extended periods of time, and if layers of protection or sacrificial wood layers are implemented, a mass timber building may survive fire without losing load bearing capacity. Other mass timber buildings that have been constructed or planned in North America include the six-story Wood Innovation Design Centre in Prince George, BC; the 12-story Framework Project in Portland, OR; and the 18-story Brock Commons Tallwood House at University of British Columbia. Worldwide, many more ambitious tall wood building projects have been announced, including conceptual designs pushing for wooden skyscrapers over 30 stories. The tallest CLT building to date is in Mjøstårnet, Brumunddal, Norway. The 85.4-meter-high Mjøstårnet (meaning "The tower of lake Mjøsa" in Norwegian) was completed in 2019. Designed by Norway's Voll Arkitekter, the 18-story mixed-use building contains a restaurant, offices, hotel rooms, and 33 apartments. The structure of Mjøstårnet consists of glulam trusses, columns, and beams, while CLT was used for stiffening elements, and to build the elevator shafts and the staircases. An even taller building is proposed in Japan. The W350 Project is a proposed wooden skyscraper in central Tokyo, Japan, announced in 2018. The skyscraper is set to reach a height of 350 (1148 feet) meters with 70 floors, which upon its completion will make it the tallest wooden skyscraper, as well as Japan's highest, over all, skyscraper. The skyscraper is set to be a mixed-used building including residential, office and retail space. It is supposed to be made of 90% wood. Steel braces will be used to enhance resistance to wind and earthquakes. The project requires 185,000 cubic meters of timber (6.5 million cubic feet) and plans to revitalize forestry and timber demand in Japan. Wooden structures are easier to rebuild or replace than concrete structures if it collapses. Two-thirds of Japan is covered by

forest, making it the 2nd most tree-covered country of the OECD (Organization for Economic Cooperation and Development) countries after Finland.

Cross Laminated Timber (CLT)-constructed buildings offers many advantages such as the potential for mass production, prefabrication, speed of construction and sustainability as an environmentally friendly and renewable construction product. Good thermal insulation, acoustic performance, and fire ratings are some additional benefits of the building system.

While CLT is recognized as an engineered wood product in the 2015 National Design Specification for Wood Construction, the seismic design parameters for buildings constructed with a CLT wall still do not exist in the U.S. model building code. For this reason, existing mass timber buildings often utilize steel or concrete lateral systems for earthquake loading.

Innovative Materials

Scientists and engineers are developing new building materials with even greater shape retention. Innovations like shape memory alloys have the ability to both endure heavy strain and revert to their original shape, while fiber-reinforced plastic wrap — made by a variety of polymers — can be wrapped around columns and provide up to 38% greater strength and ductility.

Engineers are also turning to natural elements. The sticky yet rigid fibers of mussels and the strength-to-size ratio of spider silk have promising capabilities in creating structures. Bamboo and 3D printed materials can also function as lightweight, interlocking structures with limitless forms that can potentially provide even greater resistance for buildings.

Over the years, engineers and scientists have devised techniques to create some effective earthquake-proof buildings. As advanced the technology and materials are today, it is not yet possible for building to completely withstand a powerful earthquake unscathed. Still, if a building is able to allow its occupants to escape without collapsing and saves lives and communities, we can consider that a great success.

Ductile Materials

Ductility describes how well a material can tolerate deformation before it fails. Materials with high ductility can absorb large amounts of energy without breaking. Structural steel is one of the most ductile of all materials. On the other hand, masonry and concrete are low-ductility materials, making them vulnerable materials to seismic waves. Unfortunately, unreinforced masonry (URM) is one of the most common types of partition wall systems in many buildings in North America, and many other countries around the world. URM partition walls are mostly brittle and catastrophic during an earthquake shaking. A new material has been developed called *eco-friendly ductile cementitious composite*. Sprayable Ecofriendly Ductile Cementitious Composites (EDCCs) is a form of fiber reinforced engineered cementitious-based composite material that is similar in nature to steel and when applied to URM walls greatly increases the wall's ductility. Experiments showed applying a 10-millimeter-thick layer to interior walls protected them from damage during a 9.0-magnitude simulated quake.

Another innovative material to reinforce existing URM is *carbon fiber*. Carbon fiber is the lightest and strongest material known to man. When carbon fiber straps are installed on masonry wall with an industrial-strength epoxy, it creates an unbreakable bond between the carbon fiber material and the wall surface. The result is a wall which is significantly stronger than steel.

Structural Reinforcement

There are numerous methods for reinforcing a building's structure against potential earthquakes. Commonly used *shear walls* and *braced frames* redirect seismic forces and transfer lateral forces from the floors and roof to the foundation. *Diaphragms* are rigid horizontal planes that transfer destructive lateral forces to vertical-resistant parts of the building, such as a building's walls or framework. *Movement-resistant frames* work by making a building frame's joints rigid while letting the other parts of the frame move.

Shear walls are made of panels that help a building maintain its shape during movement by transferring earthquake forces. Shear walls are sometimes supported by diagonal cross braces. There are called *braced frames*. Generally made of steel, these frames have the ability to support both compression and tension, which helps to counteract the pressure and push forces.

Diaphragms consist of the floors of the building, the roof, and the decks placed over them, and help remove tension from the floor and push the forces to the vertical structures of the building.

Moment-resistant frames allow for more flexibility in a building's design than shear walls do. Shear walls are often solid and do not allow for windows and doors. *Moment-resistant frames* are open frames that work by ensuring that the joints of the building remain rigid which allows for the columns and beams to bend without compromising the structure.

Seismic Dampers

Effective earthquake-resistance in buildings often requires shock absorbers or seismic dampers. Seismic dampers absorb destructive energy, protecting the building from sustaining it. Similar to a shock absorber on a vehicle, a piston filled with a hydraulic fluid absorbs the energy of the movement and dissipates it as heat. These are usually placed in the connection of columns to beams.

In the now destroyed World Trade Center, the dampers were made of visco-elastic material, material that was partially viscous, that is, partially flowable like oil, and also elastic, which means they act somewhat like steel, in that after being strained to deformation they return to their original shape. Construction crews placed the dampers, 11,000 of them in each building, between the bottom of the floor trusses and the columns—two parts of the building that tended to move with respect to each other when the edifice swayed. When it did so, those two parts would shear the visco-elastic dampers. This shearing caused the material to heat up, and that heat was transferred to the building.

Pendulum Power

Another damping method used in buildings, especially high-rise structures is the use of pendulums. Typically, a large ball is suspended with steel cables with a system of hydraulics at the top of the building. When the building begins the sway due to wind or seismic activity, the ball acts as a pendulum and moves in the opposite direction to stabilize the direction. The resonant frequency of a building can be calculated, and the pendulum, or *tuned mass damper*, can be tuned to counteract the building's movement in the event of an earthquake.

Seismic Invisibility Cloak

Instead of just dealing with forces once they enter a building, research is being done with ways buildings can deflect and reroute the energy from earthquakes altogether. Called the "seismic invisibility cloak", this method involves creating a cloak of 100 concentric plastic and concrete rings and burying it at least three feet beneath the foundation of the building.

As seismic waves approach the building, they enter the rings, and are forced to move through to the outer rings in the path of least resistance resulting in rerouting the waves away from the building and dissipated into the ground.

Hurricanes

A ***hurricane*** is a storm that occurs in the Atlantic Ocean and northeastern Pacific Ocean. A ***typhoon*** occurs in the northwestern Pacific Ocean. A ***cyclone*** occurs in the South Pacific Ocean or Indian Ocean. There is no difference in the specifications and dynamics of the storms. The only difference is where they occur. A ***tornado (twister, whirlwind)*** is a rotating column of air that is in contact with both the surface of the Earth and a cumulonimbus cloud.

Hurricanes are usually more destructive because of the area they cover, which can range from about 60 miles in diameter up to 1,000 miles. Tornadoes are much smaller in area affected— from 300 to 500 yards wide.

The name *hurricane* comes from the Mayan storm god *Hunraken* and the Arawak word *hurican*, which meant the "devil wind." Over 4,000 tropical storms have occurred in the North Atlantic (including the Caribbean) in the last 500 years, half of which have become hurricanes.

When a hurricane force wind blows against a building, the windward wall tends to block the air, and the air pressure increases. The force can smash doors and windows, collapse walls and support and bracing systems, or completely destroy a building.

Whereas the windward walls suffer from positive pressure, the other surfaces of the building, experience suction. If there is a window or door opening in the windward side, the high pressure can push into a building where it can blow through partitions, and even through the leeward wall. The internal pressure is helped by the external suction on all the surfaces other than the windward wall. Whole roofs can be lifted from their place. If the eye of a hurricane passes over a home, it will be subjected to winds in one direction and after the eye passes, it will be subjected to winds from the opposite direction.

Key to hurricane and tornado resistance is in strengthening the load path. Buildings are always designed to provide a continuous load path to support down-bearing gravity forces, which are compressive, pushing the parts of the house into each other. Every framing member is placed to be supported by another, and each must be strong enough to bear the downward force, which is finally transferred to the earth.

In a high-wind event, the support needs reverse. Uplift pressures work to pull the parts of the house up. These forces usually follow the same load path as for gravity loads. Buildings need to be designed to ensure that tension forces don't pull the connections apart and that shear forces don't sever the horizontal connections such as nails and screws as the framing is pulled upward.

With tornadoes and hurricanes, wind is not the only factor. Rainfall and storm surges as well the flooding that ensues is sometimes more damaging than the wind. Rainfall can damage structures by washing away walls, and by washing under foundations, or just the weight of water itself on flat and low slope roofs.

Review Questions

31. CLT is an acronym for _____.
 - a. Cross lateral torsion
 - b. Cold loaded transfer
 - c. Cross laminated timber
 - d. Class limited terminals

32. Shape memory alloys are able to both endure heavy strain and revert to their _____ shape.
 - a. Intended
 - b. Original
 - c. Estimated
 - d. Equivalent

33. Structural steel is one of the most _____ materials.
 - a. Ductile
 - b. Versatile
 - c. Rigid
 - d. Durable

34. _____ is the lightest and strongest material known to man.
 - a. Diamond
 - b. Platinum
 - c. Carbon Fiber
 - d. Nylon

35. Diaphragms in a building are usually _____.
 - a. Floors
 - b. Roofs

- c. Decks
- d. All of the above

36. Some buildings use _____ to absorb destructive energy.

- a. Springs
- b. Seismic dampers
- c. Sponges
- d. None of the above

37. Some high-rise buildings use _____ to dampen sway.

- a. Windmills
- b. Water tanks
- c. Pendulums
- d. All of the above

38. A _____ occurs in the South Pacific Ocean or Indian Ocean.

- a. Cyclone
- b. Typhoon
- c. Hurricane
- d. Tornado

Designing for Hurricane Resistance

Some main design considerations for wind resistance are:

Location

The location of the building is important. Of course, it is best to avoid building in high-risk zones at all, but sometimes we have no choice. In such cases, the best we can do is to design and build for the inevitable storm(s) by building a stronger-than-normal house reinforced to resist the forces of wind and rain.

Shape

If we don't have choice over location, we still usually do have control over the shape of our buildings and shape is a very important factor in determining the performance of buildings in hurricanes. Simple, compact, symmetrical shapes are best. The square plan is better than the rectangle. The rectangle is better than the L-shaped plan. Even more important than the shape of the plan shape is the geometry of the roof. For lightweight roofs it is best that they be hipped and with a steep pitch, with little or no overhangs at the eaves and with ridge vents.

Windows and Doors

Second to roofs, windows and doors require the most attention. Glass windows and doors are vulnerable to flying objects. There are only two solutions. Opening protection can be provided by one of two methods

- An approved impact-resistant covering capable of resisting windborne debris impacts can be installed over an existing, unprotected opening (such as a window or door).

- An approved, impact-resistant product (such as a new window or door assembly) can be installed in place of a product that is not designed to resist such forces or as an alternative to impact-resistant shutters or screens.

For new buildings there is the opportunity to design storm shutters which are integrated into the design of the overall structure. They can also be designed to have another function (*e.g.* sun shading, burglar proofing, etc.) and to even enhance the appearance of the building.

Roof and wall coverings capable of resisting high winds

Nail roof sheathing with 8d ring-shank or screw-shank nails at 4" o.c. along ends of sheathing and 6" o.c. along intermediate framing.

Protection for openings

(windows, doors, garage doors, soffits, and vents) to resist high winds, windborne debris, and wind-driven rain

Opening protection can be provided by one of two methods

- An approved impact-resistant covering capable of resisting windborne debris impacts can be installed over an existing, unprotected opening (such as a window or door).
- An approved, impact-resistant product (such as a new window or door assembly) can be installed in place of a product that is not designed to resist such forces or as an alternative to impact-resistant shutters or screens.

Structural systems providing a continuous path for all loads

(gravity, uplift, and lateral) to be passed from the building exterior surfaces to the ground through the foundation

Roof to wall connection should be Simpson H1 or equivalent uplift and shear capacity. Connectors should be attached on sheathing side of exterior walls.

Tie gable end trusses to structure with continuous 2"x4"x8' lateral braces at 6'-0" o.c.. Provide a tie strap attached with (8) 10d common nails at each end.

Continuously sheathe gable end walls with structural panels (plywood or OSB). Nail sheathing with 8d common nails at 4" o.c. along perimeter and 6" o.c. at intermediate framing.

Nail upper story sheathing and lower story sheathing into structural rim board.

Continuously sheathe all walls with wood structural panels (plywood or OSB) including areas around openings for windows and doors. Nail wall sheathing with 8d common nails at 4" o.c. along perimeter and 6" o.c. at intermediate framing

Extend wall sheathing down to top sill plate, fasten with 8d common nails at 4" o.c.

Secure post-to-beam connections with Simpson MSTA24 or equivalent

Anchor the sill plate to the foundation by installing ½” anchor bolts through 0.229x3”x3” square plate washers, minimum 48” o.c.

In addition to the aforementioned, the following recommendations are particularly appropriate for **non-engineered** construction and for **minimum cost** construction:

1. Limit height of buildings to one and two stories.
2. Ensure that lightweight floors and roofs are securely fastened to the walls to improve their performance in hurricanes.
3. The shape of the building should be, as far as possible, symmetrical which would provide a more balanced distribution of forces in the structure.
4. Provide sufficient distance between openings to avoid slender piers. Keep the openings moderate in width to avoid long-span lintels.
5. Link the heads of all walls together by providing a continuous collar or ring beam at floor and roof levels.
6. Lightweight roofs should be not less steep than 20 degrees (generally speaking, the steeper the better up to about 30 degrees) to improve their wind resistance.
7. To improve their wind resistance lightweight roofs should have a hipped shape (sloping in four directions) rather than a gable shape (sloping in two directions) or a mono-pitch shape.
8. Again, to improve their wind resistance, lightweight roofs should have minimum overhangs at the eaves, even to have no overhangs at all.. The need to shade windows and doors from sun and rain may be met by separate canopies or awnings that can break away under strong winds conditions.
9. The use of ridge vents reduces internal pressures and therefore help in keeping on lightweight roofs in a hurricane.

Wattle and Daub

Prior to European arrival in the Caribbean, most indigenous homes had low walls frequently made of wattle and daub (wooden strips “daubed” with a stucco-like mixture) with roofs usually constructed of locally harvested thatched palms. These materials were more suitable to the Caribbean climate than those initially tried by the European settlers. Stone, for example, might withstand hurricane-force winds, but it proved problematic in the heat and humidity, as well as during earthquakes, when it could rupture or crumble to the ground. Meanwhile, Wattle and daub houses could withstand hurricanes, and though the roofs might occasionally require replacement following a storm, they could be quickly and easily repaired with local materials.

Wattle and daub is one of the most common infills, easily recognizable by the appearance of irregular and often bulging panels that are normally plastered and painted. It is an arrangement of small timbers (wattle) that form a matrix to support a mud-based daub. The timbers normally fall into two groups, the primary timbers or staves, which are held fast within the frame and the secondary timbers or withies which are nailed or tied to or woven around the staves. Arrangement and sizes of panels vary from area to area as does the orientation of the staves. The daub was applied simultaneously from both sides in 'cats' (damp, workable balls) pressed into and around the wattle to form a homogeneous mass. As the daub dried it was

often keyed by scratching or 'pecking' to receive a lime plaster covering. The surface plaster was usually made of lime and sand or some other aggregate reinforced with animal hair or plant fiber. The plaster was finished flush, or in some cases, it would continue across the panels and timbers alike. This would allow less important timbers to be concealed and only principal members to be shown.

Wattle and daub is not a rigid system, but therein lies its benefit. It is able to accommodate structural movement without failure. It actually provides superior support to weaker timbers where other forms of infill might not. Wattle and daub is not lightweight or flimsy. Its weight is similar to the weight of bricks, but its insulation is better and better security since it is more difficult to break through than brick. Under the right conditions a wattle and daub panel should last a very long time. Examples of 700 years old are known to exist.

Safe Rooms

The level of occupant protection provided by a safe room is much greater than the protection provided by buildings that comply with the minimum requirements of most building codes

According to FEMA, "A safe room is a room or structure specifically designed and constructed to resist wind pressures and wind-borne debris impacts during an extreme-wind event, like tornadoes and hurricanes, for the purpose of providing life-safety protection."

Safe rooms are classified as either in-ground, above-ground, or within a basement. While in-ground safe rooms provide the inherent missile protection afforded by the surrounding soil coverage, above-ground safe rooms are required to be rigorously tested to ensure that they can also provide missile impact protection. All properly constructed safe rooms offer life safety protection when properly designed and constructed.

Safe rooms should not be built where flooding can occur which may have the potential to endanger occupants. Safe rooms with the potential to be flooded should not be occupied during a hurricane or other rain event.

Flooding

Of course, the best plan to avoid flooding is to avoid building in any area that is vulnerable to flooding. Unfortunately, one third of the entire continental United States is at risk of flooding, so to design and build with the consideration of the potential of flooding the following protective measures should be taken.

Elevate the Structure Above the Flood Level

The flood level elevation for specific areas can be found online using programs such as the *Estimated Base Flood Elevation Viewer* run by FEMA. Using this information, architects can calculate how high to raise the building. The most common way of elevating is by building the structure on columns, piers, pilings, or stilts, or a traditional solid foundation can be built higher.

Build with Flood Resistant Material

Flood resistant materials are those which can last in contact with flood waters for at least 72 hours without 'significant damage.' 'Significant damage' is defined by any damage requiring more work than just cleaning or low-cost cosmetic repair, such as painting. Flood resistant materials should be durable and resistant to extreme humidity.

Floodproofing

There are two types of floodproofing: dry and wet. Dry floodproofing prevents flood waters from ever even entering the structure. Wet floodproofing allows flood waters to enter the building, but in such a way as to prevent damage to the structure. Dry floodproofing is achieved by the use of coatings, membranes, sealants, and other waterproof barriers. A waterproof barrier can consist of a layer of masonry sealed with a waterproof membrane, protecting the exterior walls against water penetration. Wet Floodproofing includes permanent or contingent measures applied to a structure or its contents that prevent or provide resistance to damage from flooding while allowing floodwaters to enter the structure. This includes securely anchoring the structure, using flood resistant materials below the Base Flood Elevation (BFE), protection of mechanical and utility equipment, and use of openings or breakaway walls. According to FEMA, application of wet floodproofing as a flood protection technique under the National Flood Insurance Program (NFIP) is limited to enclosures below elevated residential and non-residential structures and to accessory and agricultural structures that have been issued variances by the community.

Raise HVAC Equipment and Mechanical, Plumbing, and Electrical System Components

Service equipment may be protected from damage from flooding, by the use of waterproof enclosures, barriers, protective coatings, or other means, but all of these methods are prone to failure. The best way to protect flood damage is to locate the service equipment above the flood protection level. Such equipment includes heating, ventilating, air conditioning, plumbing appliances, plumbing fixtures, duct systems, and electrical equipment including service panels, meters, switches, and outlets. If any of these components are exposed to floodwater, they can become severely damaged and in the case of electrical equipment, there is the potential risk of fire if short circuited

Anchor Fuel Tanks

Unmoored fuel tanks float and are easily moved by flood waters. Once afloat, tanks can crash into other objects damaging the object and the tank itself. A damaged petroleum tank could contaminate flood waters and create a potential medium for fire. A damaged LP tank could risk a devastating explosion. Even buried tanks can be pushed to the surface due to buoyancy. Therefore, all fuel tanks should be anchored, either by attaching them to concrete anchors that are heavy enough to resist flood water forces, or strapping them to ground anchors.

Construct Permanent Barriers

A permanent barrier that is placed around a building can prevent flood waters from reaching it. Such barriers should be constructed using a floodwall made of concrete or masonry, or by using

a levee made of compacted layers of soil with an impervious core. Both floodwalls and levees require extensive maintenance.

Install Sewer Backflow Valves

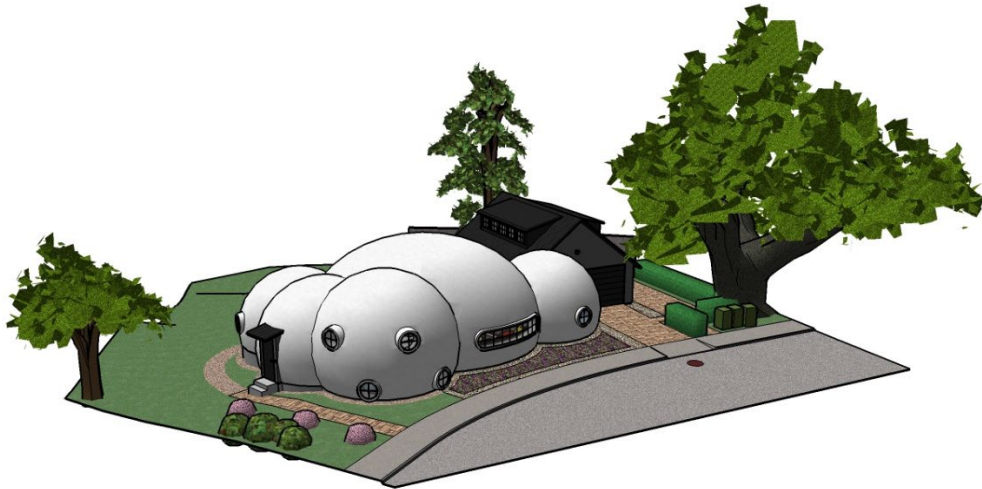
Sewer backflow valves prevent flooded sewage systems from backing up into a home. In certain flood-prone areas, this issue is common, and can cause damage that is both difficult to repair and hazardous to occupants' health. Generally, gate valves are preferred over flap valves because they provide a better seal against flood pressure.

Grade the Lawn Away from the House

Sloping the grade away from the building should be done in every case. It is not only a deterrent to flooding, but it prevents surface water from becoming ground water which can exert significant hydrostatic pressure against foundations and basements. As a minimum the angle of slope should be 1" per 1'-0" away from the building.

Domes

The dome is by far the best shape for earthquake and hurricane resistance.



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Footings

Depending on soil bearing capacity, geotechnical reports and any optional subgrade reclaim tunnels, a continuous circular ringbeam foundation is engineered and constructed. When complete, all material and equipment needed for the monolithic dome construction are moved into position inside the foundation.

A custom fabricated waterproof exterior roofing membrane is attached to the footings and inflated. Depending on the size of the dome, this process takes minutes to a couple hours.

Insulate

Once inflated, the monolithic dome construction process is completed from inside the dome, avoiding costly weather delays. The polyurethane foam insulation applied provides initial

rigidity and a thermal barrier from the outside elements protecting the concrete and dry bulk storage product from extreme freeze-thaw cycles and condensation.

Rebar

Rebar is attached to the foam providing additional rigidity and a skeleton structure for the concrete. Additional layers will be placed in the dome depending on the engineering specifications.

Shotcrete

With the first mat of rebar hung, shotcreting begins. Shotcrete is applied in thin concentric layers intermittently with the installation of additional cages of rebar and until depth gauges are covered.

IMMEDIATE RESPONSE SHELTERS

“POP-UP” STRUCTURES

When responding to the immediate situation after a disaster event, it is important that people see action as soon as possible, both for physical protection and safety and for emotional encouragement. Promises with procrastination and inaction cause the people to be discouraged and to distrust those who are trying to help.

Materials should be minimal, inexpensive, and able to be on site as soon as possible. If possible, construction methods should be kept simple, so that the victims of the disaster can perform most, if not all, of the actual construction themselves.

SURVIVAL STRUCTURES – Low tech

Following is a list of some of the simplest forms of shelters.

Body-Heat Shelters - Shelter can be described as a shell that traps a pocket of dead air warmed by body heat.

- *Debris Hut* – Mound of decomposed leaf litter and other organic debris with an excavated pocket that is large enough to crawl into.



- *Quinzhee Hut* – this can be called a poor man’s igloo, it is made of snow and should be made tall enough so you can sit up



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Open Shelters structures that reflect a fire’s warmth are the most important shelters to know how to build. They can be erected without tools in an hour provided you are in an area with downed timber

- *Pole and Bough Lean-to* – Considered to be one of the most ancient shelters, the lean-to will serve as a windbreak, fire reflector, and overhead shelter.



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- *A-Frame* – Offers the most protection against the wind and can be heated by a fire at the entrance.



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Enclosed Shelters take longer to build than open shelters and can be warmed by a small fire

- *Wickiup* is like a tipi made from poles, brush, and vegetation.



- *Wigwam* – A dome dwelling built with long, limber poles. This is a semi-permanent structure with curved surfaces making it an ideal shelter for all kinds of conditions.



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- *Salish Subterranean Shelter* – These shelters are not the most practical solution because of the necessity of digging a 3 foot in depth pit; but they offer a higher level of protection from extreme temperatures, both cold and hot.



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You can learn more about building these structures at the following website:
<https://www.fieldandstream.com/photos/gallery/survival/shelter/2006/10/seven-primitive-survival-shelters-could-save-your-life/>

SURVIVAL STRUCTURES – High tech

An example of a higher tech survival structure is a temporary relocatable shelter that is a modular, lightweight, rugged, sometimes insulated, and easy to set up space. This type of structure usually comes as a complete kit and many times requires the use of one or two tools. These shelters typically are long-lasting and have a surprising amount of usable space with a minimal footprint. Each component is lightweight making it easy for anyone to be able to set it up. Whether in snow or sun, these provide shelter and relief from the elements.

Case study: HAITI 2010 earthquake

The population of Haiti is about 11,603,684 as of Tuesday, December 14, 2021. The ethnic groups of the population are 93.8% African descent, 5.4% Mulatto and 0.8% other. There is also an Asian minority and Arabs. Haiti has a total area of 27,750 km²; most of it is in the western third of the Hispaniola island and the rest are smaller islands that are near the Haitian coast, such as Gonâve, Île de la Tortue, Les Cayemites, Île-à- Vache and La Navase.

There are many mountains in Haiti, with only some coastal plains and few valleys; the largest valley is the *Cul-de-Sac*, where Port-au-Prince is found on its western end. The main Haitian river is the Artibonite, which is also the longest on the Hispaniola Island. The biggest city is Port-au-Prince with more than 3 million in the metropolitan area; the second largest city is Cap-Haïtien. The rain season is from April to June and from October to November. Tropical cyclones and hurricanes are common during the summer months and they have resulted in tremendous human suffering.

Haiti is currently the least developed country in the Americas. Even before the devastating earthquake, the country was among the world's poorest and least developed. There are certain economic indicators that can be calculated to compare the social and economic situation of different countries. Some of these indicators show that Haiti has fallen behind other low-income developing countries since the 1980s. In 2006, Haiti ranked 146th of 177 countries in the United Nations Human Development Index (2006). About 80% of the population was estimated to be living in poverty in 2003. Haiti is the only country in the Americas on the United Nations list of Least Developed Countries.

About 66% of all Haitians work in the agricultural sector. Most of them do small-scale subsistence farming, but this activity makes up only 30% of the GDP. In the last ten years, very few jobs were created, but the informal economy is growing. Mangoes and coffee are two of Haiti's most important exports. Haiti has consistently ranked among the most corrupt countries in the world on the Corruption Perceptions Index.

Foreign aid makes up approximately 30%-40% of the national government's budget. The largest donor is the United States followed by Canada, and the European Union. Venezuela and Cuba also make various contributions to Haiti's economy, especially after alliances were renewed in 2006 and 2007.

Earthquake Impact

The earthquake on 12 January 2010 struck Haiti at the heart of its capital, Port-au-Prince, as well as in the Villages of Léogâne, Jacmel and Petit-Goâve. The damage and losses, which grew every day, are estimated to be nearly 8 billion USD according to the most recent assessment of losses and damages.

Impact on Human Life

The human impact is immense. Roughly 1.5 million people, i.e. 15 percent of the national population, were directly affected. According to the official Haitian Government estimates, more than 300,000 died and as many were injured. About 1.3 million people are still living in temporary shelters in the Port-au-Prince metropolitan area. Over 600,000 people have left the affected areas to seek shelter elsewhere in the country. Existing problems in providing access to food and basic services have been exacerbated. By striking at the very heart of the Haitian economy and administration, the earthquake had a severe effect on human and institutional capacities, both the public and the private sectors, as well as international technical and financial partners and some non-governmental organizations (NGOs).

Impact On Infrastructure

The destruction of infrastructure is colossal. About 105,000 homes were totally destroyed and over 208,000 were damaged. More than 1,300 educational institutions and more than 50 hospitals and health centers have collapsed or are unusable. The country's main port has been greatly disabled. The Presidential Palace, Parliament, law courts, and most ministerial and public administration buildings have been destroyed.

Impact On the Environment

Although environmental indicators were already at warning levels, the earthquake has put further pressure on the environment and natural resources, thus increasing the extreme vulnerability of the Haitian people.

Other Factors Contributing to The Earthquake Devastation

Very soon after the earthquake it was obvious that such a toll could not be the outcome of just the force of the tremor. It is also due to an excessively dense population in urban areas, a lack of adequate building standards, the disastrous state of the environment, disorganized land use, and an unbalanced division of economic activity. The capital city, Port-au-Prince, accounts for more than 65 percent of the country's economic activity and 85 percent of Haiti's tax revenue.

Overall Damages and Losses Caused By Earthquake

Overall damage and losses caused by the earthquake on 12 January 2010 are estimated to be USD 7.9 billion, which is just over 120 percent of the country's GDP in 2009. In fact, since the common-global method for estimating damage and losses was first devised 35 years ago, this is the first time that the cost of a disaster is so high in relation to the country's economy.

Most damage and losses were felt by the private sector (USD 5.5 billion, i.e. 70 percent), whereas there was USD 2.4 billion of damage and losses in the public sector (i.e. 30 percent of the total).

The value of destroyed physical assets, including housing units, schools, hospitals, buildings, roads, bridges, ports, and airports, is estimated to be USD 4.3 billion (55 percent of the overall cost of the disaster). The effect on economic flows (production losses, reduction of turnover, loss of employment and wages, increase in production costs, etc.) was USD 3.6 billion (equivalent to 45 percent of total).

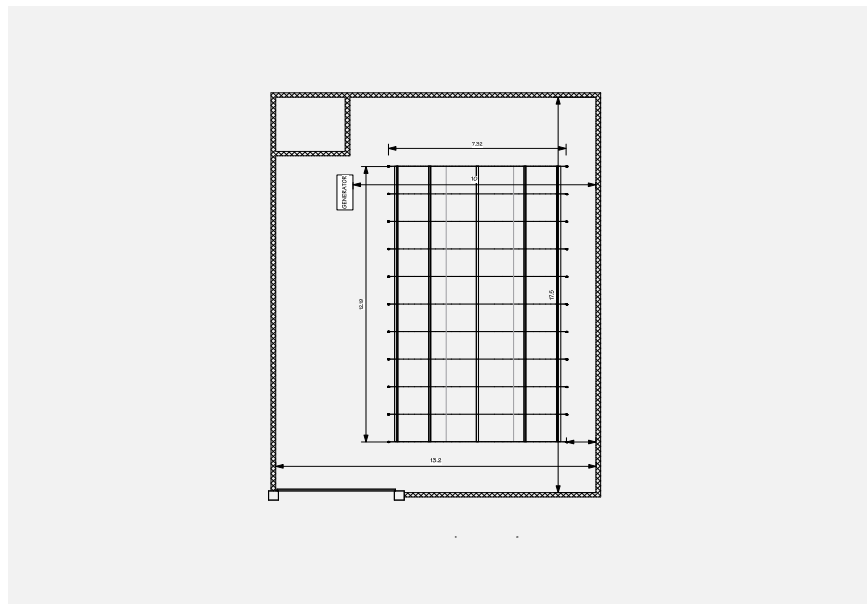
According to the Haitian government, after the earthquake of January 12, 2010, “there were 1.2 million people in 460 spontaneously organized camps. Of these, 250,000 people were living in 21 of these camps presenting major risks for the well-being and safety of their inhabitants.”¹ Since Haiti is vulnerable to hurricanes, it was important to establish shelter for these people that was quickly accessible, affordable, and resistant to the natural elements that threatened them. In addition to the obvious physical challenges, there were also social needs to be addressed. Structures that gave the displaced people of Haiti personal dignity and planning that made communities possible and manageable were also matters of high priority. The proposed design that follows is an attempt to address those needs.

¹ section 4.3.1 of the action plan for national recovery and development of Haiti - key initiatives for the future (March 2010)

IMMEDIATE RESPONSE

A “pop up” pavilion

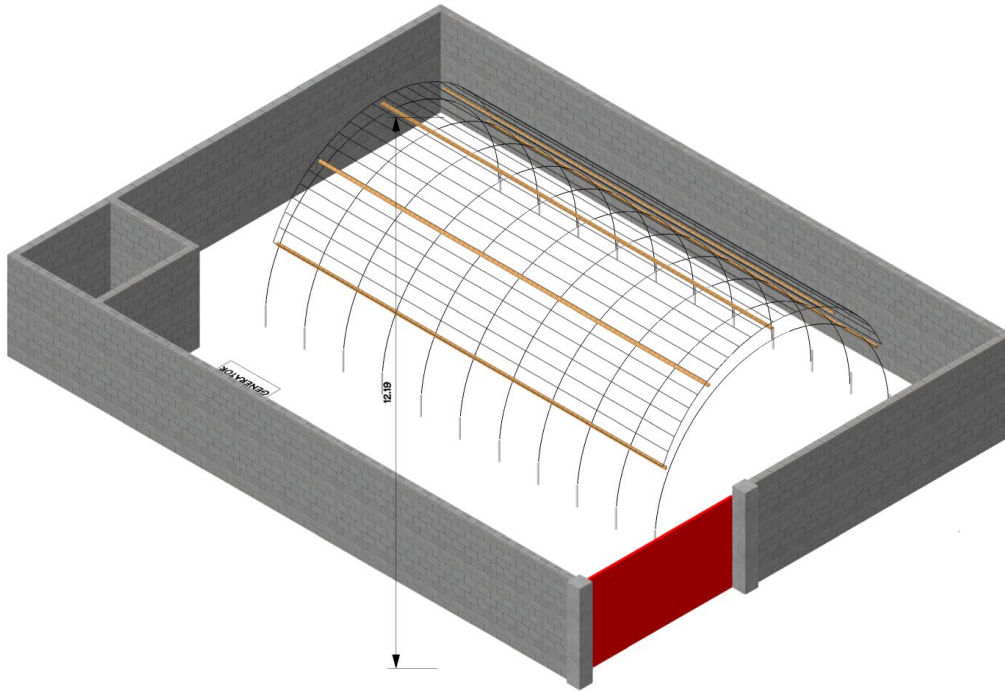
The environment of Haiti is year-round heat and because the forests were harvested years ago to produce charcoal, there is very little vegetation. The goals are simple – get people *off the ground* and *out of the sun*. Complete enclosure is not important, in fact, in many cases, it is not even desirable.



The site was a roughly 43' X 57' walled lot in the village of Titanyen, Cabaret, Haiti, with a dug-out latrine in the corner.



The materials used were 14' X 48' billboard "vinyls" that had been rejected due to copy issues such as misspellings or color defects. Since they were to be discarded, the cost was zero. They were imported to the site from the US by Americans flying on commercial aircraft carrying military style duffle bags.



The framework was 2-1/2" PVC electrical conduit bent into semi-circular arches. The arches were formed by inserting the ends of the conduit into chain link fence terminal posts that had been driven into the ground.



The ribs of the frame were held in position with ropes that maintained the spacing and stabilized by guying to posts driven into the ground.



The billboard vinyls were stretched over the frame and lashed to the arches for the roof. Other vinyls were used as ground cloths, spread and spiked to the ground for a finished floor.

Under the direction of the designer, the entire building was erected in a single day using only the citizens of the village as labor.

The elderly women of the village brought their folding chairs into the shade of the space immediately upon completion and began socializing with one another.

The next morning the women and children of the village decorated the pavilion with flowers and streamers and five couples were married in a combined wedding ceremony in the afternoon.

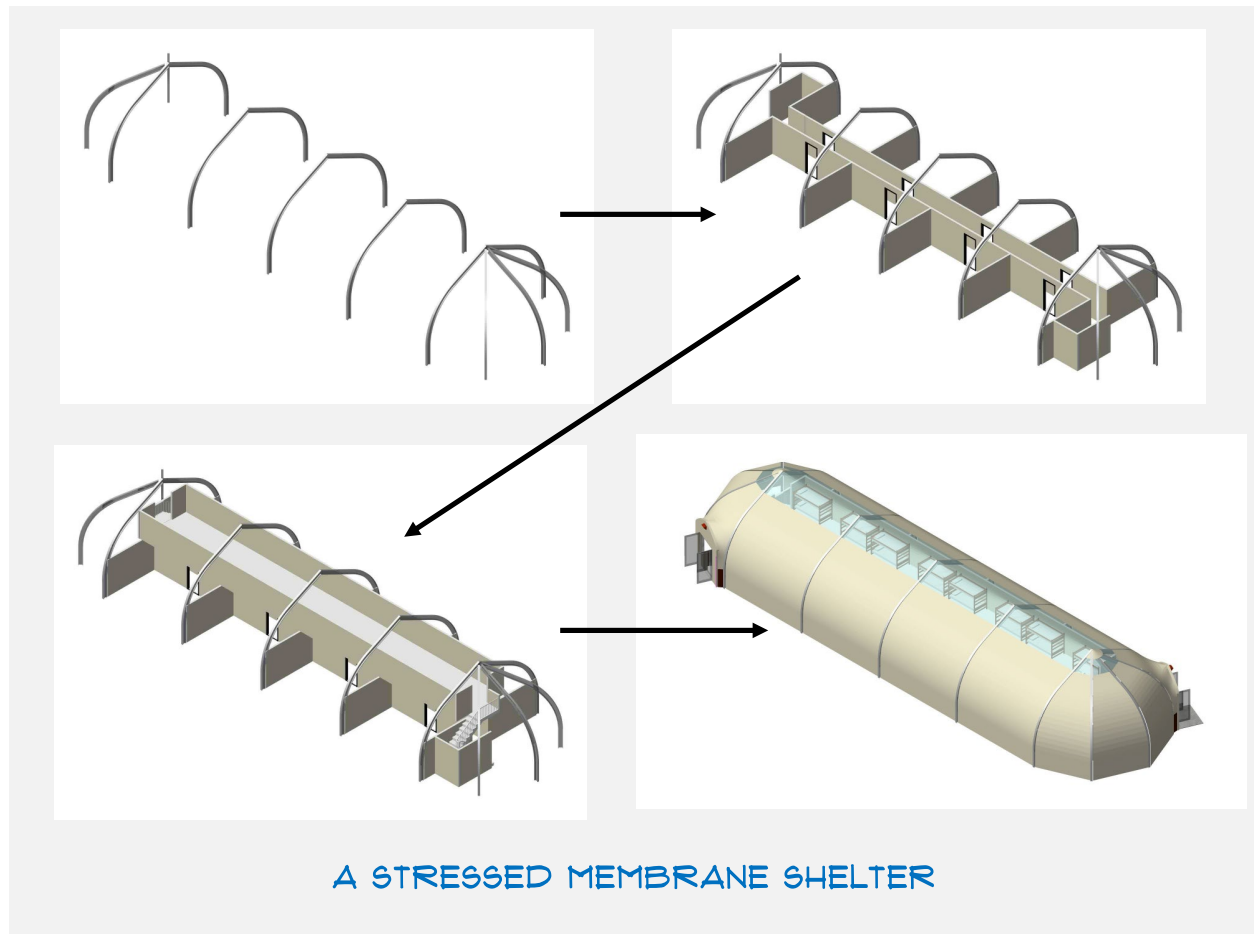
In less than 72 hours responders had left the United States with materials, the pavilion was constructed, and utilized for community socialization and ceremonial purposes.



In a very short period of time, a group of people who were down and dejected were encouraged and proud of the job they had done to meet the needs of their community.

As a side note, nine months after the weddings in the pavilion, one of the brides who a voo-doo witch doctor had cursed with barrenness, gave birth to a healthy child.

SHORT TERM RESPONSE STRESSED MEMBRANE STRUCTURES



Similar in some respects to the pop-up pavilion constructed with conduit and billboards, stress membrane structures are fabric membranes stretched between aluminum ribs. They can be bolted to concrete slabs or secured to the ground with earth anchors.

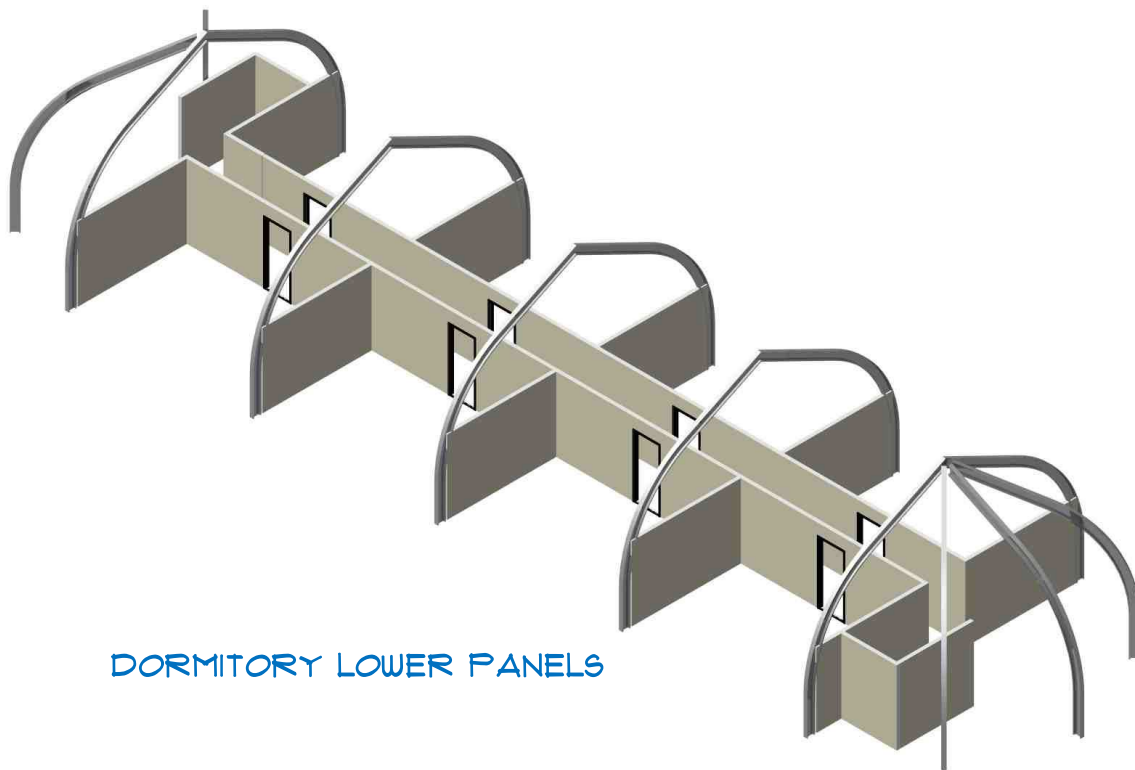
There are many advantages to using stressed membrane structures for disaster relief. Because of their relative light weight and small parts, they are easily shipped and transported to sites, even remote and sites that are difficult to access. Assembly of the arches and erection is speedy and can be accomplished with local workers, both skilled and unskilled. The aluminum frames can be bolted to monolithic slabs or secured to natural grades with earth anchors. Spans up to 200' wide and unlimited lengths can be accomplished.

Insulated structures are extremely efficient to heat and cool due to the minimal thermal bridging in the frame. Depending on the climate, stressed membrane structures can last decades and can also be dismantled and relocated. They are also uniquely resistant to hurricanes and tornadoes. The Missile Defense System integrated architecture at Fluor Alaska Inc., located in Shemya, Alaska, is engineered to withstand wind loads of 120 mph. The Warwick

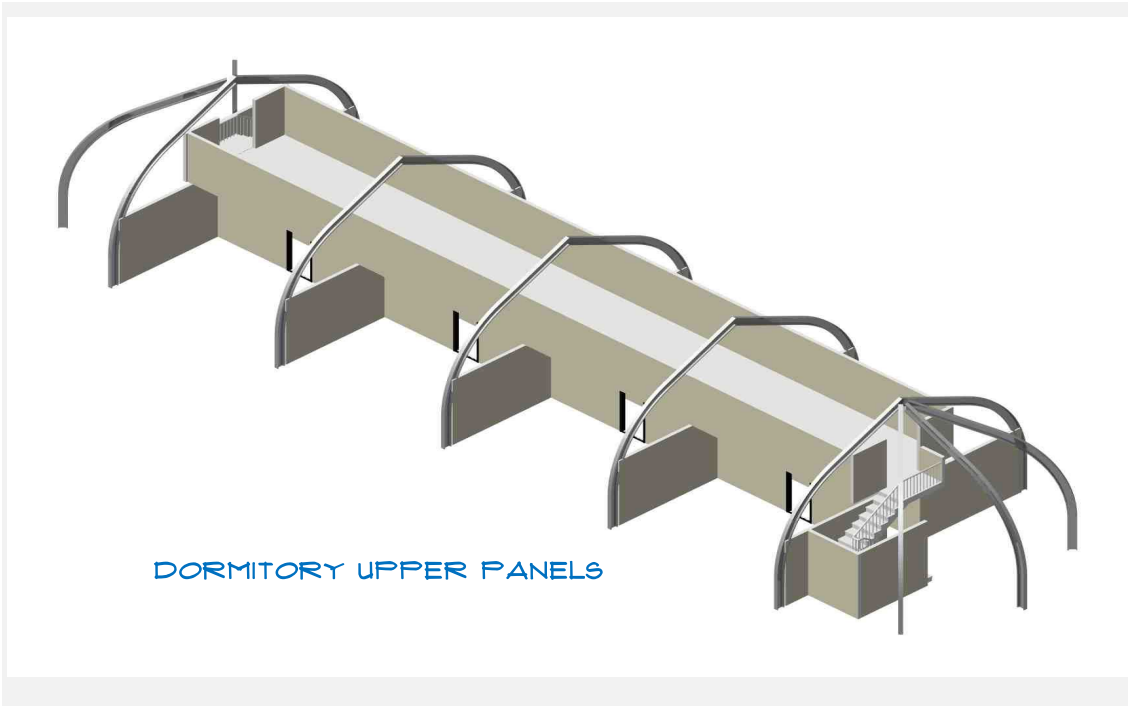
Le Lagon Resort in Vanuata in the southwest Pacific was used as a storm shelter on March 13, 2015, during Cyclone Pam, a category 5 cyclone.

Stressed membrane building manufacturers generally supply a technician that can supervise a crew of unskilled workers to erect the structures, providing the disaster victims employment and a sense of pride and accomplishment.

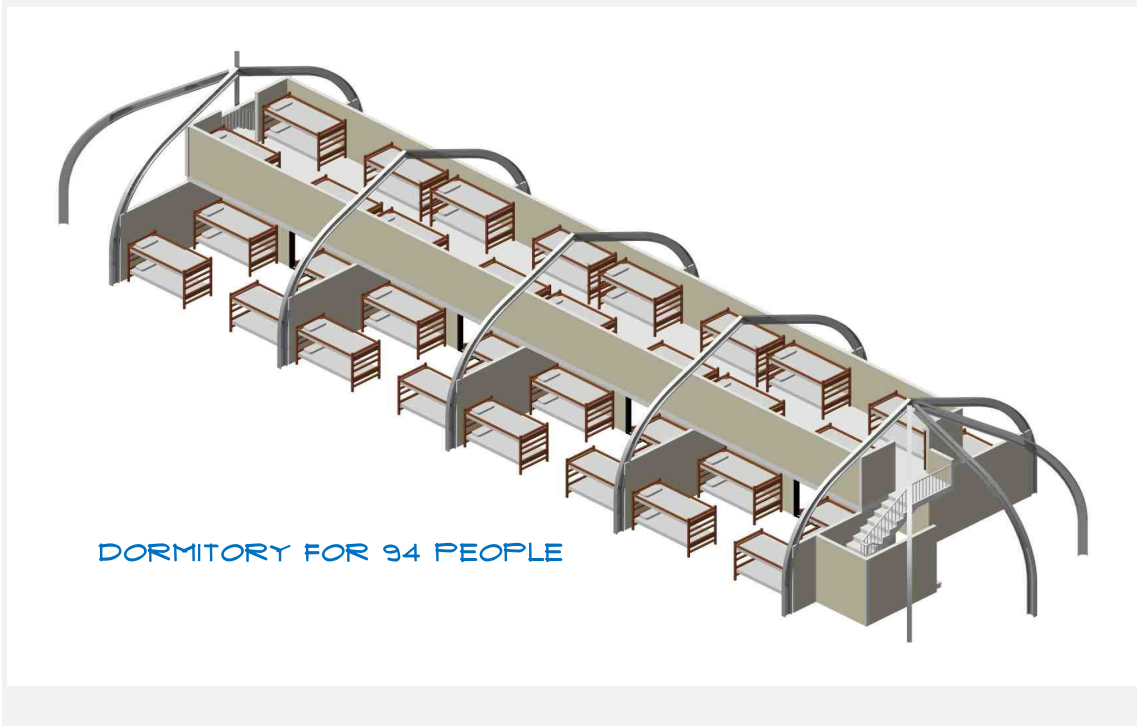
Interior configurations can be for any purpose or occupancy. This configuration is for a dormitory.



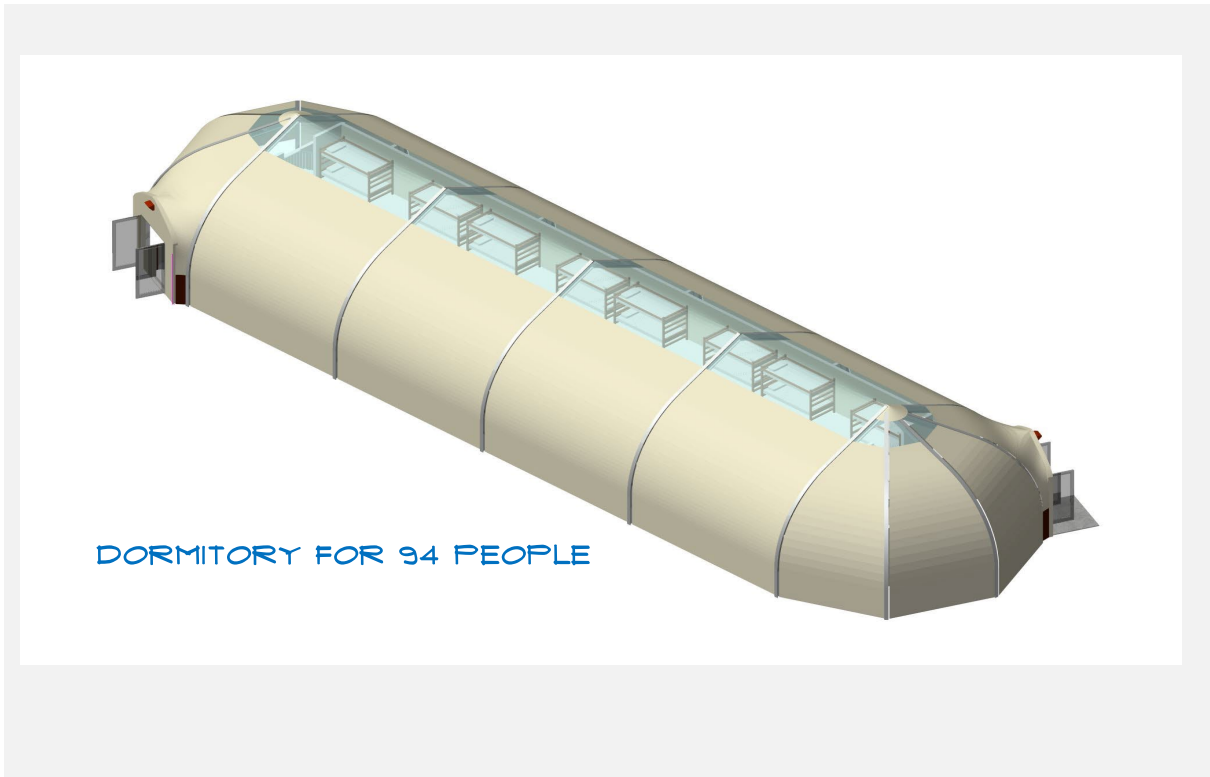
These are the walls for the ground floor.



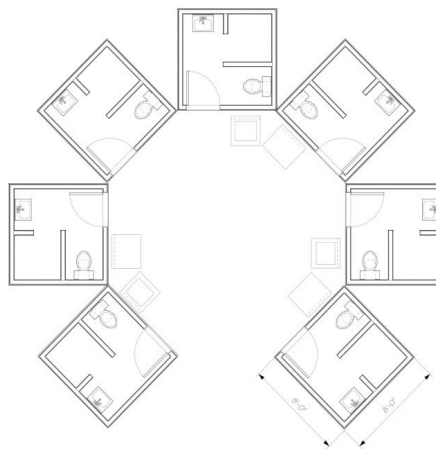
These walls are for the upper floor.



Each room downstairs sleeps 8 occupants, while the upper level sleeps 32 for a total of 96 people.

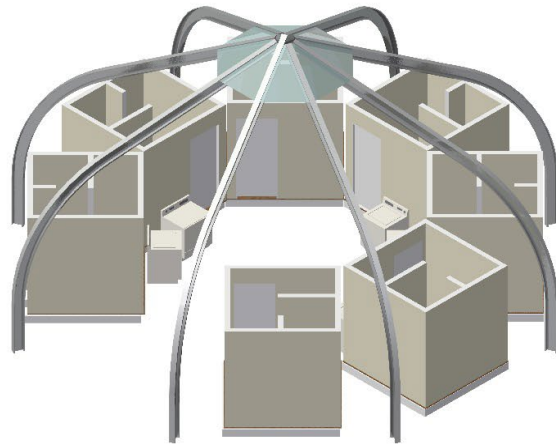


Finished dormitory with stressed membrane and translucent skylight panels.



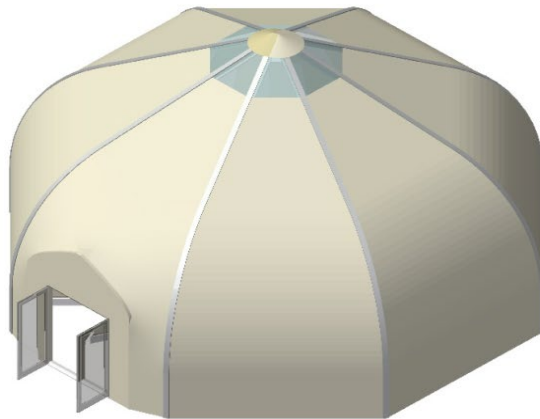
TOILET / SHOWER / LAUNDRY POD PLAN

Since this particular dormitory configuration does not include toilet/lavatory/shower rooms, a separate dedicated structure with bathrooms and laundry facilities must be supplied.



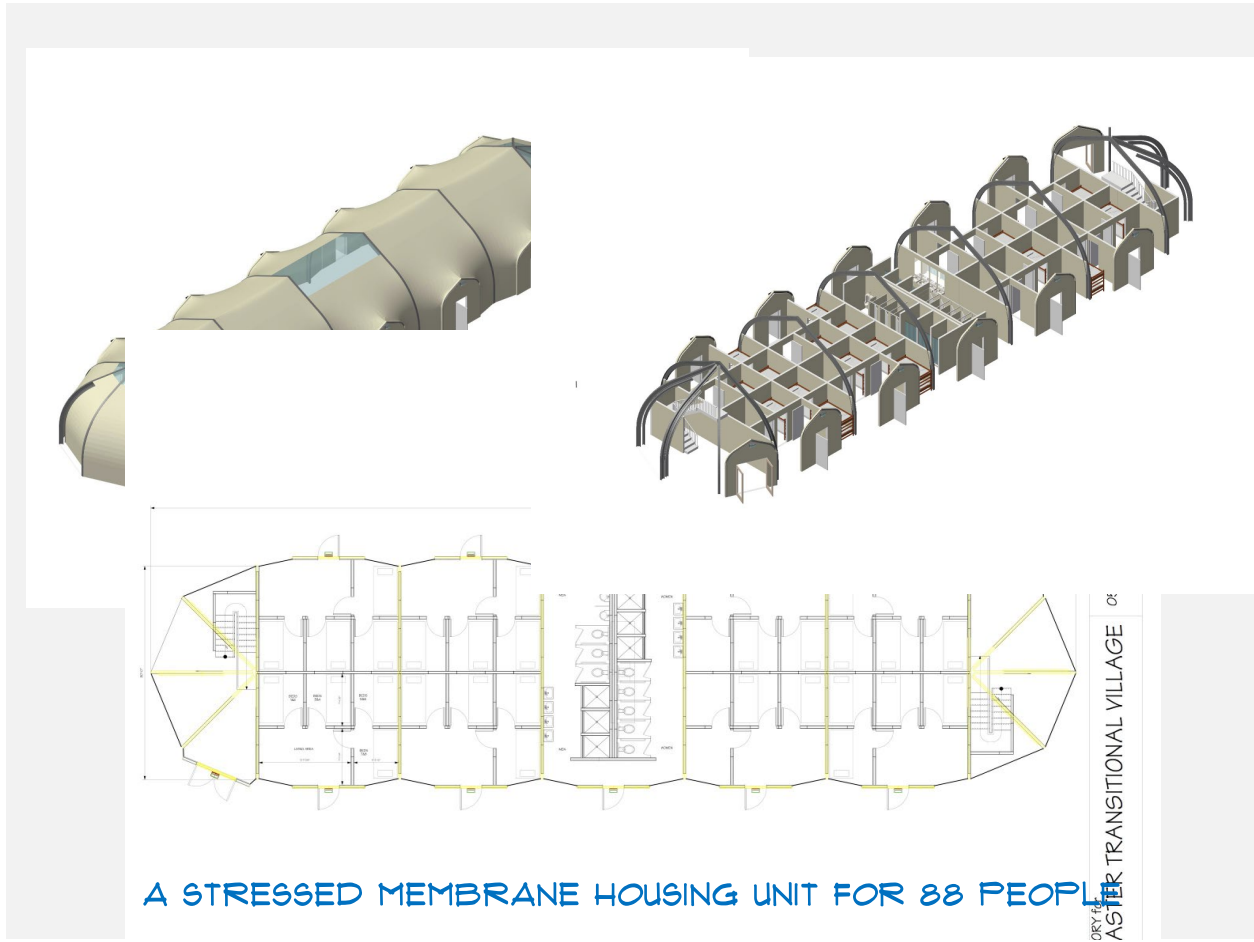
TOILET / SHOWER / LAUNDRY POD

The frame and walls for a seven-unit bathroom facility with two washers and dryers.

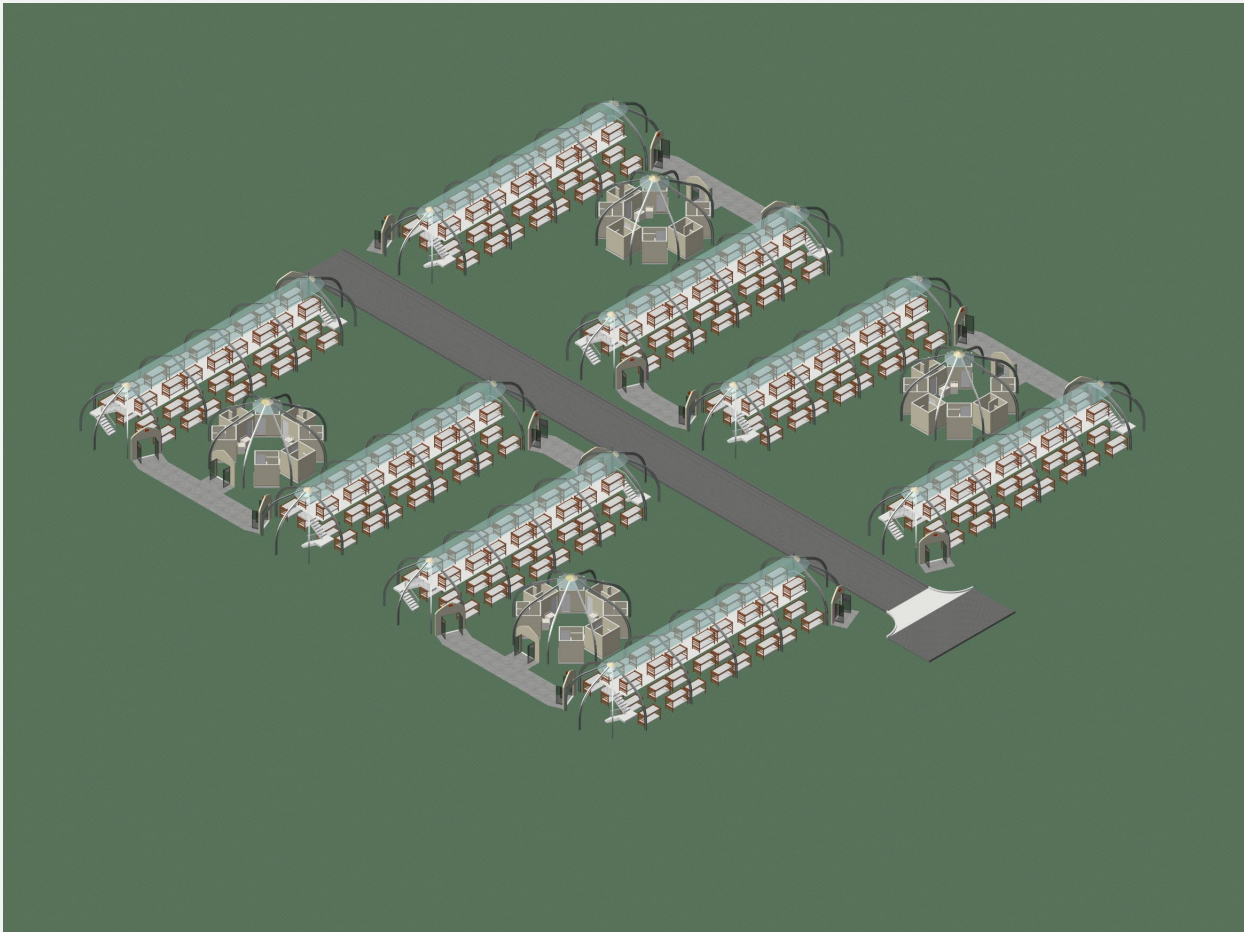


Toilet / Shower / Laundry Pod

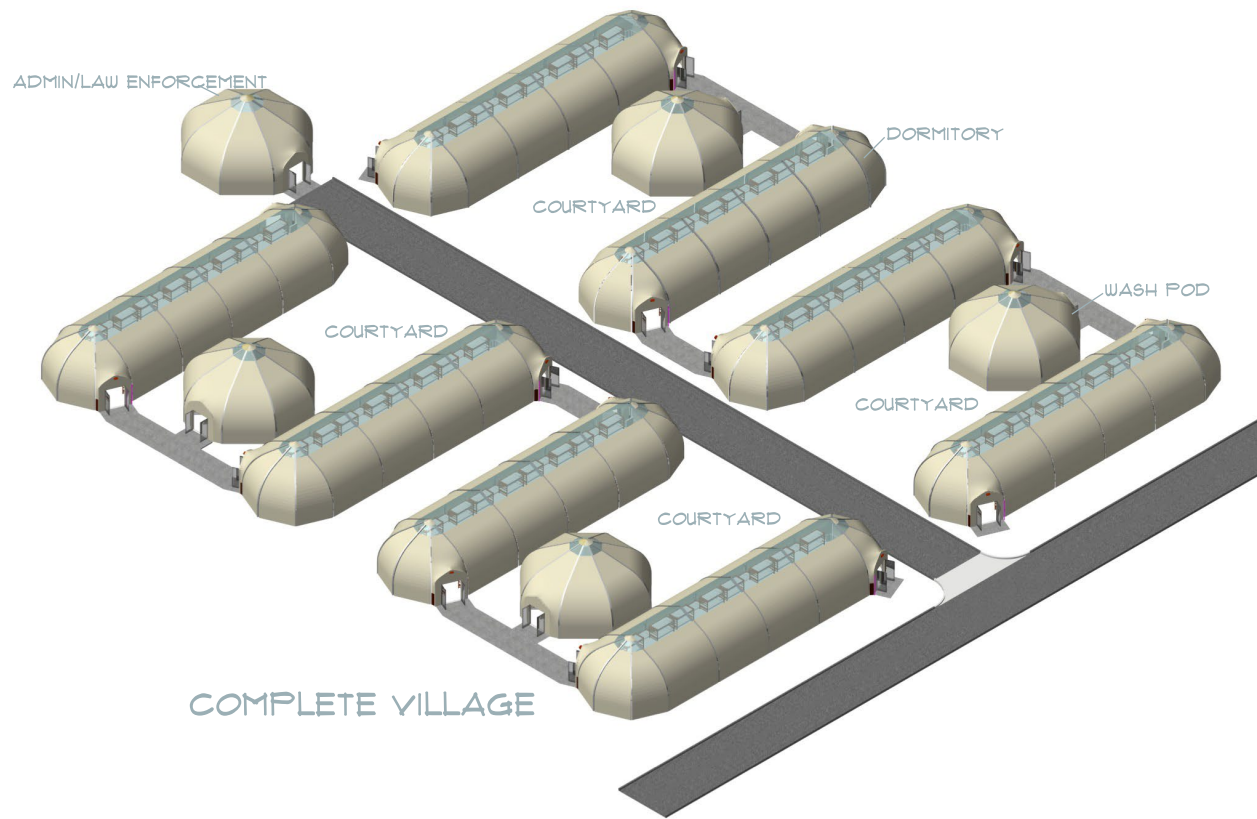
The completed toilet/shower/laundry pod.



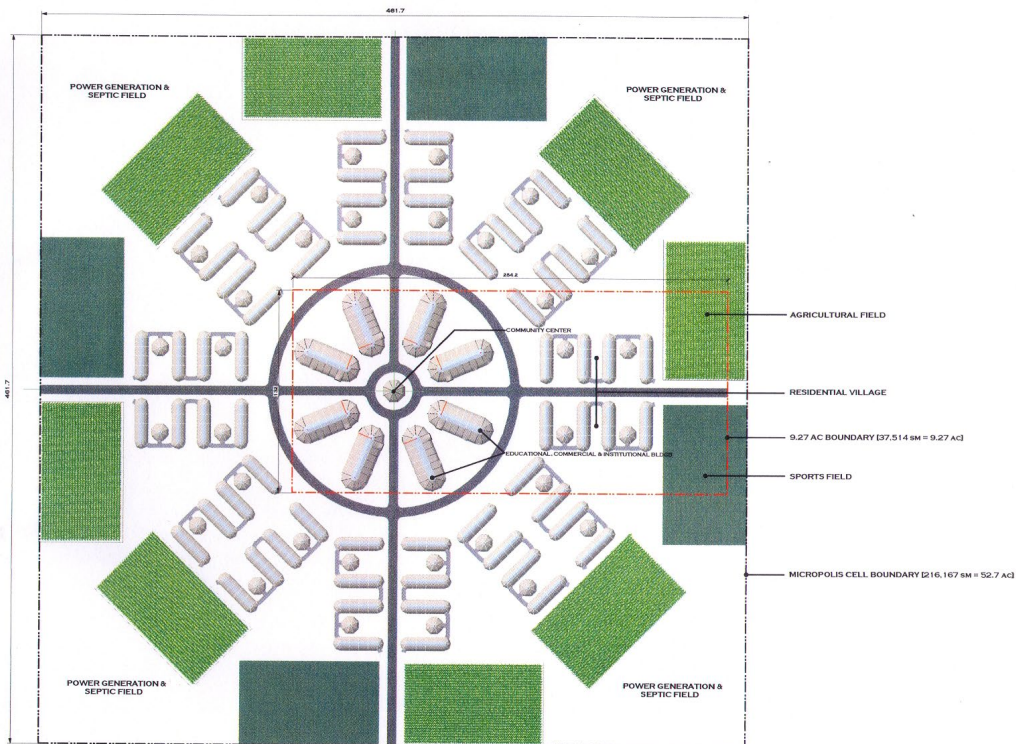
Whereas the dormitory configuration is suitable for single adults and teenagers, this configuration is for family units with separate apartments with exterior entrances and a central bathhouse.



Dormitory and family housing buildings are paired with a shared bath/laundry pod and arranged to create courtyards for outdoor cooking and social congregation. This is the normal way Haitians congregate.



Each village would be anchored with an administration and law enforcement pod.



11.04.2010

A PLAN FOR A MICROPOLIS CELL FOR
UNE NOUVELLE HAÏTI
TITANYEN, HAÏTI

Multiple villages can be arranged around institutional, education, and commercial zones creating a micropolis cell.

This 53 acre micropolis cell would have a population of 6,400 people providing housing, commercial, educational, and administrative buildings. Each quadrant would also have areas for recreation and agriculture.



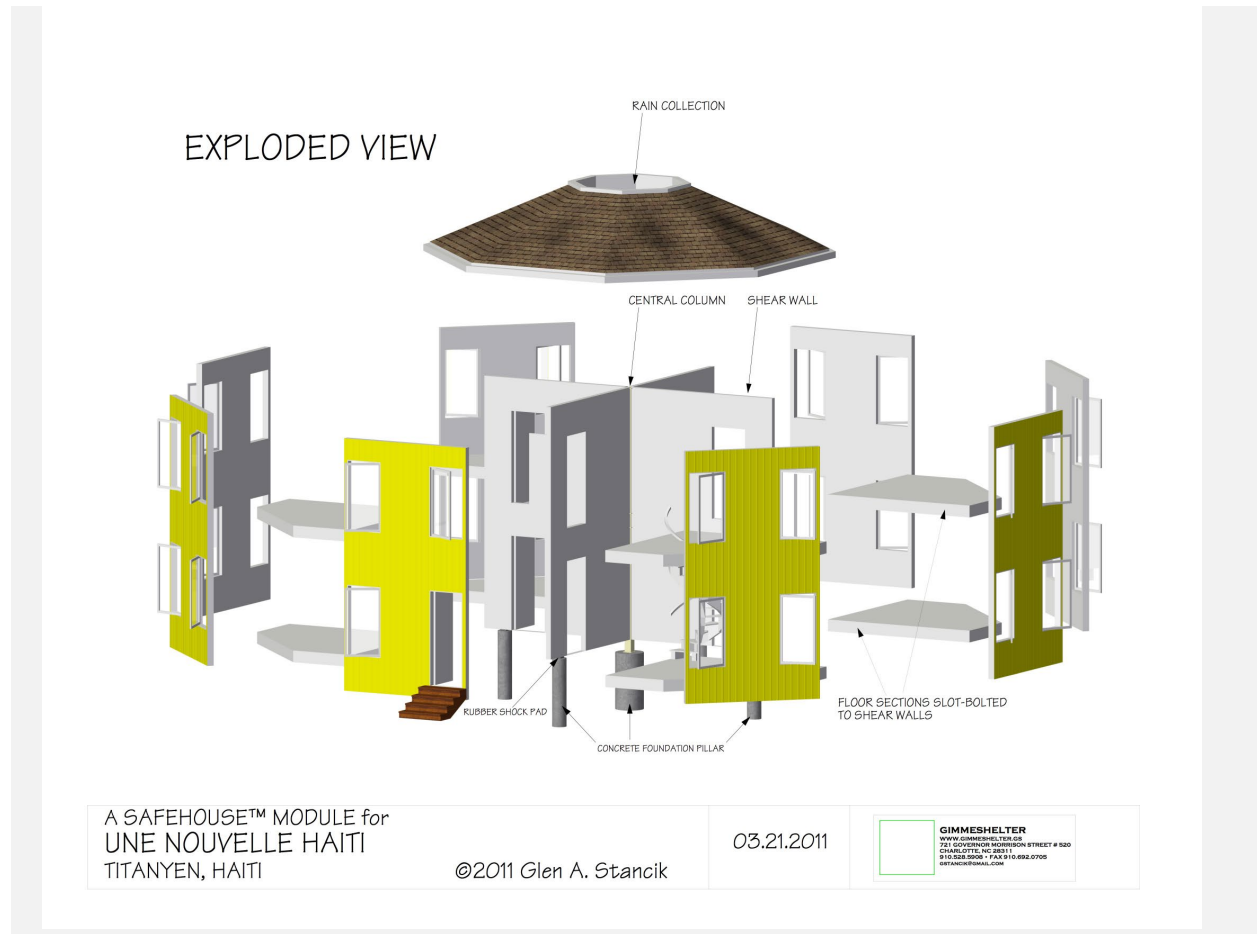
DINING FACILITIES



MEDICAL FACILITIES

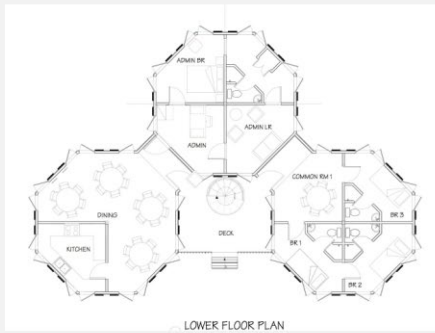
In addition to the examples demonstrated here, the buildings can be used effectively for other applications including, but not limited to health care facilities, schools, and civic and governmental facilities.

SHORT TERM RESPONSE SAFEHOUSE MODULES

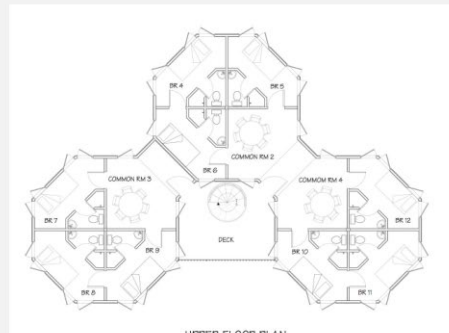


The Safe House™ module is designed on the structural principle of a plant. Rather than the building being supported on structural perimeter walls, the building is supported on a central stalk. Sheer walls hang on the central column and the floors sections are connected with bolts that can shift within slots to accommodate seismic and wind forces. Exterior wall panels are attached to the floor sections.

The plan is octagonal to minimize corners so that winds will more easily flow around the structure. There is no perimeter foundation that could be washed away with flooding and the house is elevated to allow flood waters to flow unobstructed under the building. Roof overhangs are breakaway so that they will not contribute to roof uplift. The roof is built to collect rainwater in a tank that can be used for washing. Rinse water is collected in a gray water tank. The gray water can subsequently be used to flush toilets.



LOWER FLOOR PLAN

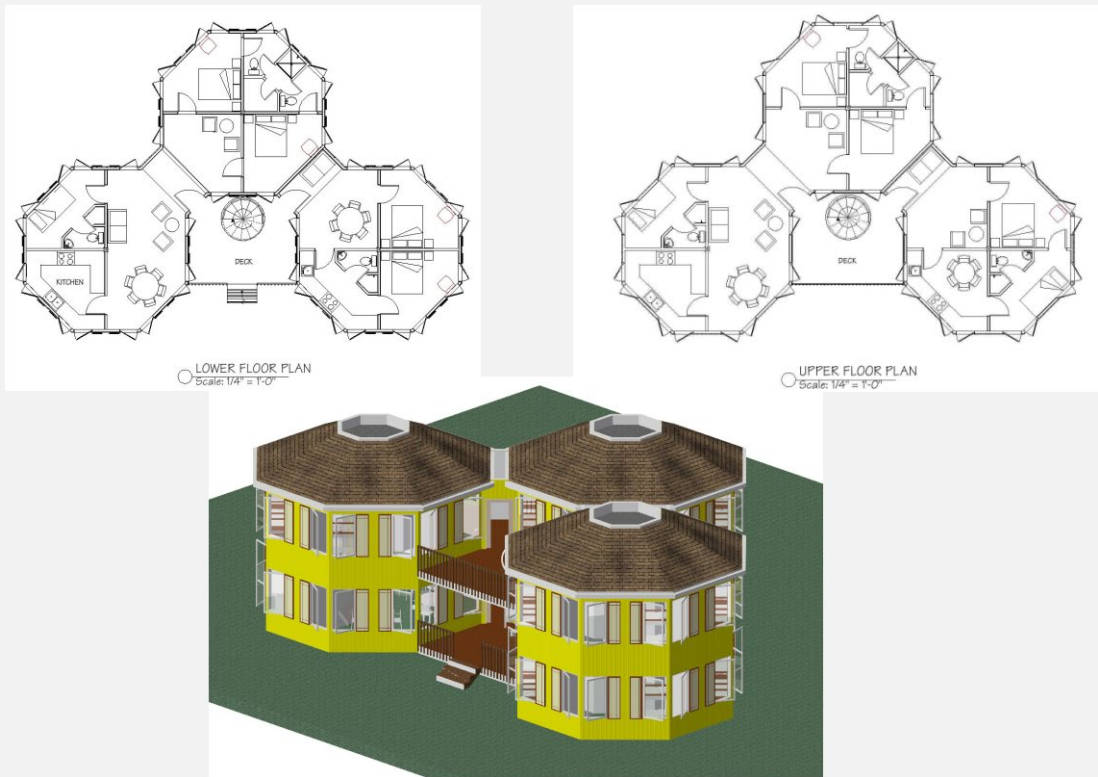


UPPER FLOOR PLAN



A tri-mod SafeHouse™ cluster configured for a 24 resident orphanage

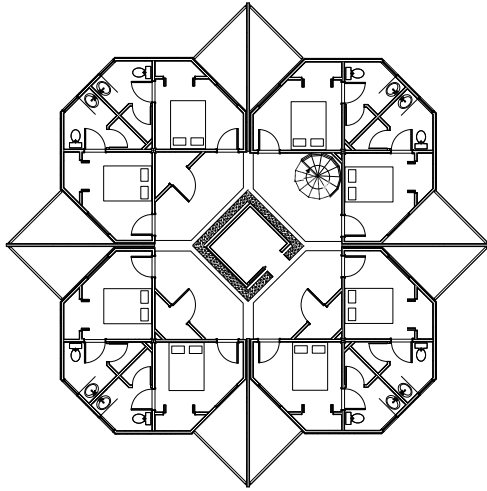
The plan of the modules can be configured to suit its occupancy and the modules can be arranged like cells in a honeycomb to create complexes from the individual modules. This plan and configuration is for a twenty-four resident orphanage.



A tri-mod SafeHouse™ cluster configured for an apartment building

This plan and configuration is for an apartment building.

A TYPICAL 8 ROOM FLOOR FOR A SAFEHOUSE™ HOTEL



COMMISSIONED BY:
EVANGELINE STANCİK
ARCHITECTURE & INTERIORS
PORT-AU-PRINCE, HAITI

05.03.2011

A TYPICAL FLOOR FOR A SAFEHOUSE™ HOTEL FOR
EVANG, PAUL
PORT-AU-PRINCE, HAITI © Glen A. Stancik 2011



SafeHouse™ Hi-Rise Hotel

© Glen A. Stancik 2011

This plan and configuration is for a high rise hotel.

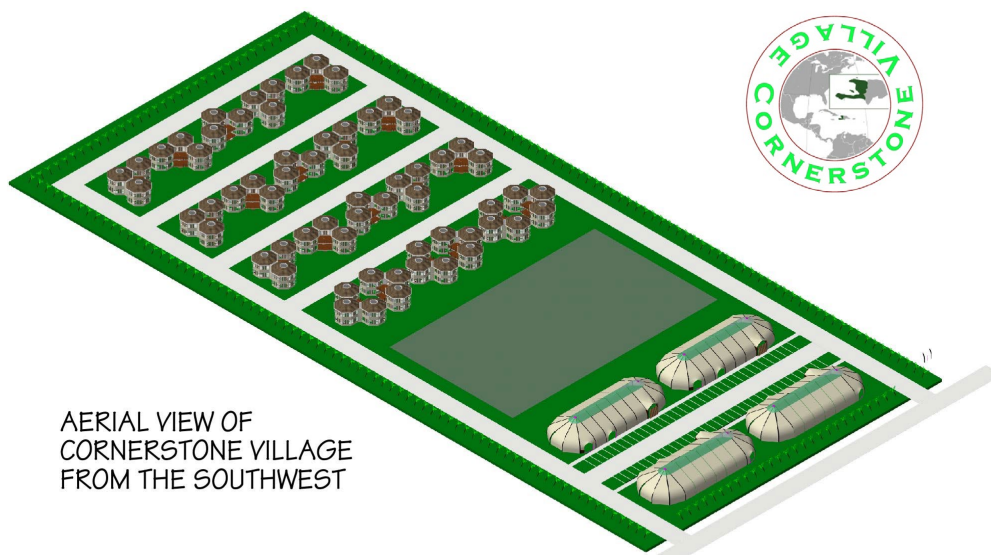


<p>A SITE PLAN for UNE NOUVELLE HAITI CORNERSTONE VILLAGE TITANYEN, HAITI</p>	<p><small>This site plan and the building designs included in it are the intellectual property of Glen A. Stancik of Charlotte, North Carolina.</small> <small>Reproduction of this design, either in whole or in part, including any form of copying, distribution, dissemination, preparation of derivative works, translation, for any reason without prior written permission, is strictly prohibited. Construction of any building using SafeHouse™ modules is also prohibited without prior consent of the Designer.</small></p>	<p>03.11.2011</p>	<p>GIMMESHALTER <small>721 CORNERSTONE WOODBURN AVENUE # 100 CHARLOTTE, NC 28203 919.238.2568 • FAX 919.482.0205 GIMMESHALTER.COM</small></p>
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This site plan was for a development to be built near the village of Lafiteau on Port-au-Prince Bay 19 km northwest of Port-au-Prince. It utilizes Safe House™ construction as well as stressed membrane structures for public spaces. Lafiteau is a port town and home to notable processing plants, including the Caribbean Mills Processing Plant and the Grain Processing Plant. The residences were intended for employees of the processing plants.

The earthquake of 2010 left many children orphaned, so the care for orphans is a regular part of Haitian community life. Twenty-five percent of the population of this development would be orphans.

Victims of the Haitian presidents Papa Doc and Baby Doc Duvalier were buried in mass graves in Lafiteau, as were 100,000 victims of the 2010 earthquake.



AERIAL VIEW OF
 CORNERSTONE VILLAGE
 FROM THE SOUTHWEST

<p>A SITE PLAN for UNE NOUVELLE HAITI CORNERSTONE VILLAGE TITANYEN, HAITI</p>	<p><small>This site plan and the building designs included in it are the intellectual property of Glen A. Stancik of Charlotte, North Carolina.</small> <small>Reproduction of this design, either in whole or in part, including any form of copying, distribution, dissemination, preparation of derivative works, translation, for any reason without prior written permission, is strictly prohibited. Construction of any building using SafeHouse™ modules is also prohibited without prior consent of the Designer.</small></p>	<p>03.11.2011</p>	<p>GIMMESHALTER <small>721 CORNERSTONE WOODBURN AVENUE # 100 CHARLOTTE, NC 28203 919.238.2568 • FAX 919.482.0205 GIMMESHALTER.COM</small></p>
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An aerial view of the development from the southwest.

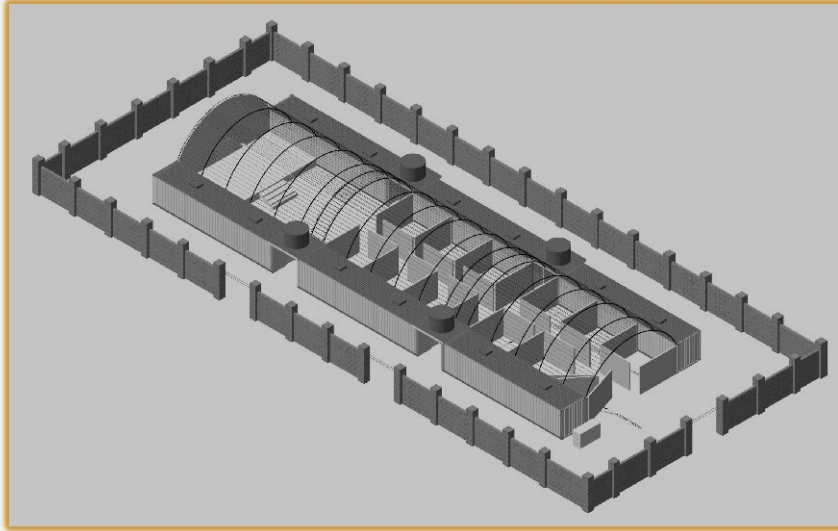
SHORT TERM RESPONSE USING ISO CONTAINERS



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The use of ISO shipping containers for purposes other than their intended purpose has become popular. ISO or Intermodal Containers are large, standardized shipping containers, designed and built for intermodal freight transport, meaning these containers can be used across different modes of transport – from ship to rail to truck – without unloading and reloading their cargo. They are essentially modular storage “rooms”. They are built to withstand extreme environments. There are currently over 17 million shipping containers in circulation globally. Used containers for purchase can cost anywhere between \$1,400-\$2,600, depending on the size and condition of the container, making them an affordable option for disaster relief applications. They are also ideal for transporting, even to remote locations.

MULTIPURPOSE FACILITY



- Car taker Residence Office Kitchen/Baker y
- Inter net CafE Dormitor y Washr oom Facilit ies
- Chur ch/Sc hool Spaces

This multipurpose facility is constructed using six 40' containers separated by a 30' space which serves as a common agora which can be used a marketplace on market days, an assembly space for religious services or civic meetings. This space is roofed using greenhouse hoops which can be covered with a membrane or OSB and EPDM or TPO single ply membrane. Hinged panels secured to the sides of the containers can be used to divide the courtyard into classrooms for weekday school classes.

MULTIPURPOSE FACILITY



LONG TERM RESPONSE USING DOMES

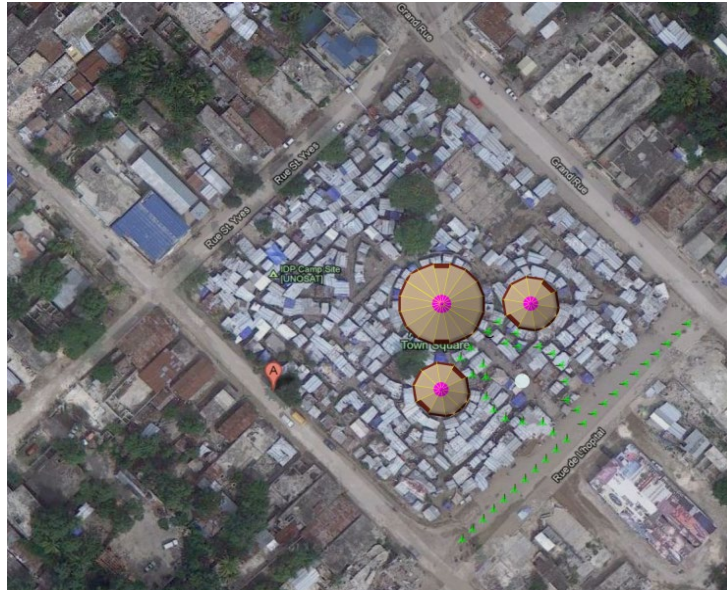
Leogane



Leogane was the epicenter of the 2011 earthquake in Haiti. 80-90% of all the buildings were destroyed. As the municipal buildings were all destroyed, the city hall was moved to a telecommunication building for temporary location.

Upon request by the mayor of Leogane, I made a proposal to establish a new city center for the town. Before I visited the site, I examined satellite photos of the city. I noticed an unusual grouping of three circles in the main square of the town. A shanty town had been established on the grounds, but the circles had somehow been respected. The best I could ascertain was that the ancient stone circles were the ruins of a central city plaza or perhaps they were cisterns or fountains associated with a fabled 500-year-old church to the city's patron saint, Sainte Rose de Lima.

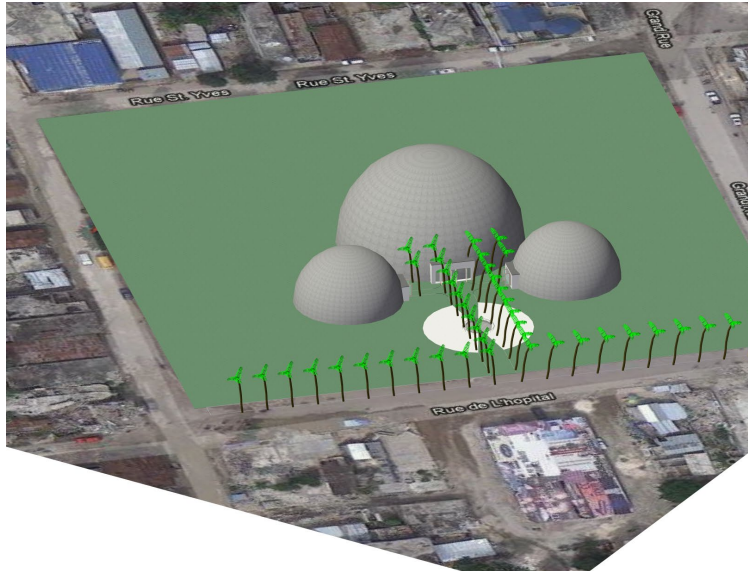
The shapes and the adjacencies of the circles seemed to be an ideal template for a site plan for a new town hall



The first proposed structures would be stressed membrane structures (SMS) which could be erected quickly. The projected use of the SMS buildings would be 5-10 years. The main structures would be the town hall for the office of mayor and administrative departments. The outlying buildings would house law enforcement including a jail and a civic center for community functions and events.



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The more permanent solution would be to replace the SMS buildings with concrete domes. The dismantled SMS buildings could be relocated and repurposed for other uses.

Since Leogane was particularly vulnerable to earthquakes (the first total destruction of Leogane by an earthquake was in 1770), it was appropriate that dome architecture be the prevailing type of building for the area.

SUMMARY

Natural disasters like hurricanes, floods, tornadoes, earthquakes and wildfires happen every year. According to an American Institute of CPAs survey conducted by The Harris Poll in the fall of 2019, six in ten Americans believe they are likely to be personally impacted by a natural disaster in the next three to five years.

When disasters strike, people's lives are overturned by the loss of lives and property. Houses and other buildings are accounted as some of the greatest losses. Without buildings, people find themselves without shelter, privacy, security, and a sense of identity. Architects are uniquely gifted and trained to design the buildings that disaster victims need. It is both a privilege and a responsibility to do so.

Designing in the aftermath of a disaster is no different than any other situation, except that the parameters of limitation are very different. The need for shelter is the same. So is the need for a dignified design that respects the humanity of those that will inhabit our designs. Time and costs parameters will, however, be drastically different. The environmental and site conditions will also be quite different. Some conditions will be so unique they are almost unimaginable.

After a disaster, there are three essential timely responses – *immediate*, *short term* and *long term*.

Immediate

When responding to the immediate situation after a disaster event, it is important that people see action as soon as possible, both for physical protection and safety and for emotional encouragement. Materials should be minimal, inexpensive, and able to be on site as soon as possible. If possible, construction methods should be kept simple, so that the victims of the disaster can perform most, if not all, of the actual construction.

Short Term

After the immediate needs are met, an intermediate or short-term response should be planned and executed. This would include both temporary structures as well as a rudimentary community planning including roads, activity specific zoning, and infrastructure easements.

Long Term

Long term response would include analysis and evaluation of historical and traditional building materials and methods as well as consideration of contemporary and futuristic materials and methods. The traditional buildings and infrastructure that has been destroyed may provide a nostalgic desire to return to the past but advances in new materials and methods should not be ignored, since a prime objective for future development will be to prevent or at least to protect as much as possible from a similar disaster.

A primary consideration to post-disaster designs is what *caused* the disaster. Any effective design must account for the earthquake, wind, or flood forces that may obtain in the future. Once emergency problems have been solved, there exists an opportunity to design houses, buildings, and cities that in the future will provide not only physical protection, but psychological, emotional, and aesthetic satisfaction as well.

Review Questions Answer Key

1. The American psychologist who created the Hierarchy of Needs was _____.

- a. Abraham Lincoln
- b. Sigmund Freud
- c. Abraham Maslow**
- d. Carl Jung

a. is an American, but not a psychologist. b. and c. are psychologists but not American. C. is correct answer.

2. Fukushima was a hybrid disaster with an earthquake, _____, and a nuclear meltdown.

- a. Cyclone
- b. Tsunami**
- c. Typhoon
- d. Tornado

a., c., and d. are types of storms. b. is a tidal wave caused by an earthquake.

3. Many of the people who died in the Indonesian tsunami of 2004, died because of _____.

- a. Starvation
- b. Dehydration
- c. Drowning
- d. Exposure**

d. is correct answer because the tsunami occurred in December causing many to die of exposure.

4. The three responses after a disaster are _____, short term, and long term.

- a. Immediate**
- b. Longevity
- c. Brief
- d. Overall

The responses are points on a timeline; therefore a. is the correct answer.

5. After a disaster people prefer to rebuild _____.

- a. A different location
- b. On higher ground
- c. The place where they lived before the disaster**
- d. Near an escape route

c. is the correct answer because people are attached to their locations and want to resume life where they are familiar.

6. Successful reconstruction is usually done by _____.

- a. Experts
- b. General contractors
- c. NGOs

d. The victims themselves

*Even though experts, general contractors, and NGOs can be **effective** at reconstruction, **successful** reconstruction is best done by those who have suffered the loss.*

7. The Japanese word for “lonely death” is _____.

- a. Hari kari
- b. Kamikaze
- c. Kodokushi**
- d. Sudoku

a. is honorable suicide, b. is intentional suicidal airplane crash, and c. is a number game. d. is the correct answer.

8. The greatest loss people suffer from disasters is their _____.

- a. House
- b. Belongings
- c. Home**
- d. Employment

a., b., and d. are all specific important physical losses, c. includes mental and emotional aspects.

9. Ancient humans found shelter in _____.

- a. Caves
- b. Hollows of trees
- c. Huts

d. All of the above

While a., b., and c. are not comprehensive, the list is inclusive.

10. In addition to being familial, humans are also _____.

- a. Psychological
- b. Social**
- c. Emotional
- d. Competitive

Social is familial writ large.

11. The Romans standardized the width of their roads for _____.

- a. Livestock
- b. Chariots
- c. Aqueducts

d. Two-way traffic

Livestock and chariots could navigate narrower roads, but two-way traffic required wider and standardized roads.

12. Often short term housing solutions are like _____.

- a. Villages
- b. Camps**
- c. Towns
- d. Cities

a., c., and d. are natural, organic social organizations of human living and activity. Camps are quickly put together but often inhuman.

13. The earth's crust is divided into a series of very large plates, called _____ plates.

- a. Tectonic**
- b. Dental
- c. Geological
- d. Geographical

c. and d. refer to the earth, but not the plates. B. is facetious.

14. Most earthquakes occur along lines of weakness in the earth's crust, which are termed _____.

- a. Cracks
- b. Fissures
- c. Faults**
- d. Crevasses

a., b., and d. occur in many places on the earth's surface, but are not necessarily associated with earthquakes.

15. The Circum-Pacific Belt is often referred to _____.

- a. Circle of Death
- b. Pacific Ring of Fire**
- c. Volcano Row
- d. Pacific Triangle

The terms "circum" and "Pacific" are obvious clues.

16. An increase of 1 unit on the Richter scale represents an increase by approximately _____ times.

- a. 2
- b. 4
- c. 16
- d. 32**

Because the scale is logarithmic, in terms of energy, each whole number increase corresponds to an increase of about 31.6 times the amount of energy released.

17. *Tsunami* is a Japanese word for “ _____”.

- a. Sushi
- b. Earth shake
- c. Harbor wave**
- d. Coastal storm

A tsunami is a wave caused by an earthquake. C. is the only answer that includes a wave.

18. When designing building in seismic areas, it is best to avoid _____.

- a. Irregular plans
- b. Asymmetrical designs
- c. Split level structures
- d. All of the above**

While a., b., and c. are not comprehensive, the list is inclusive.

19. To protect from earthquakes, it is necessary to _____ the foundation from the earth.

- a. Integrate
- b. Isolate**
- c. Elevate
- d. Levitate

Since damage to buildings by earthquakes is caused by forces coursing through the structure, the best tactic is to isolate the building from the earth.

20. A lighter structure undergoes _____ damaging force than a heavier one.

- a. More
- b. Less**
- c. Equal
- d. None of the above

Once dynamic forces act on a building, heavier buildings will generate stronger forces.

21. For a building material to resist stress and vibration, it must have high _____.

- a. Resilience
- b. Compression
- c. Ductility**
- d. Rigidity

Ductility is the ability of a material to change shape without losing strength.

22. _____ is the most widely used construction material in the United States.

- a. Concrete
- b. Steel
- c. Aluminum
- d. Wood**

Due to its availability, ease of use, and relative price advantage, wood is widely used in the US

23. A Haitian architecture which originated in the late-19th century is the _____ house.

- a. Painted lady
- b. Gingerbread**
- c. Victorian
- d. Hurricane

While a. and c. were late 19th century styles of houses, they were not used in Haiti. Gingerbread houses were designed to accommodate the conditions of Caribbean weather conditions.

24. Wood-frame construction provides numerous _____ paths through shear walls and diaphragms.

- a. Load**
- b. Critical
- c. Extreme
- d. Resistance

Shear walls and diaphragms are load bearing components; therefore a. is the correct answer.

25. The 1994 _____ Earthquake was a milestone for engineering of wood structures.

- a. San Francisco
- b. Tacoma
- c. Northridge**
- d. San Andreas

The last San Francisco earthquake was 1989. An earthquake occurred near Tacoma in 2001. San Andreas is a major fault line. The Northridge quake occurred in 1994.

26. In 2000, the first International _____ Code was published by the International Code Council.

- a. Building
- b. Administrative
- c. Electrical
- d. Residential**

All choices are codes, but a. is the code published by the ICC in 2000.

27. Soft-stories have _____.

- a. Large doors
- b. Garage doors
- c. Large windows
- d. All of the above**

Soft stories are considered "soft" because of their vulnerability due to large openings.

28. Diaphragms and shear walls are used to transfer _____.

- a. Forces
- b. Loads**
- c. Frames
- d. Vibrations

Shear walls and diaphragms are load bearing components; therefore b. is the correct answer.

29. _____ construction is a system of construction using many small and closely spaced members.

- a. Braced framing
- b. Heavy framing
- c. Arkansas framing
- d. Light framing**

a. and b. are framing systems that use heavy members, c. is a system using widely spaced members. D. is the correct answer.

30. Balloon framing is sometimes called _____ framing.

- a. New York
- b. Boston
- c. Chicago**
- d. Denver

Balloon framing was invented in the 1830s in Chicago.

31. CLT is an acronym for _____.

- a. Cross lateral torsion
- b. Cold loaded transfer
- c. Cross laminated timber**
- d. Class limited terminals

No explanation needed.

32. Shape memory alloys have the ability to both endure heavy strain and revert to their _____ shape.

- a. Intended
- b. Original**
- c. Estimated
- d. Equivalent

Since the shape of members is designed to withstand the loads it must resist, it is necessary to return to the originally designed shape.

33. Structural steel is one of the most _____ materials.

- a. Ductile**
- b. Versatile
- c. Rigid
- d. Durable

Of all the properties steel is known for, ductility is the main property.

34. _____ is the lightest and strongest material known to man.

- a. Diamond
- b. Platinum
- c. Carbon Fiber**
- d. Nylon

Developed in 1860 to be used in light bulbs, carbon fiber was developed in 1958 to be used a structural material.

35. Diaphragms in a building are usually _____.

- a. Floors
- b. Roofs
- c. Decks
- d. All of the above**

While a., b., and c. are not comprehensive, the list is inclusive.

36. Some buildings use _____ to absorb destructive energy.

- a. Springs
- b. Seismic dampers**
- c. Sponges
- d. None of the above

Seismic vibrations from earthquakes become destructive energy in buildings and must be dampened.

37. Some high-rise buildings use _____ to dampen sway.

- a. Windmills
- b. Water tanks
- c. Pendulums**
- d. All of the above

Pendulums counteract the tendency for buildings to sway due to wind or earthquake forces.

38. A _____ occurs in the South Pacific Ocean or Indian Ocean.

- a. Cyclone**
- b. Typhoon
- c. Hurricane
- d. Tornado

A tropical system in the Atlantic and northeast Pacific is called a hurricane. In the south Pacific and northern Indian ocean, they're called cyclones. A tropical system in the northwest Pacific is called a typhoon.