ABSTRACT

Title of Document: **DESIGN FOR DISASTER DISPLACEMENT**

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Due to the increase in occurrence of natural disasters, it is imperative for our society to learn to maintain resiliency, while also preparing for the aftermath of a disaster. The major tasks of this proposal include providing emergency and permanent housing, within a condensed timeframe to a medium density while providing communal spaces and activities for long term use. New York City, the epicenter of the region and the country, can be catastrophically damaged by an earthquake or hurricane, particularly because of the density of population and lack of awareness of seismic risk. The quality of pre-disaster planning immediately results in a more successful post-disaster reconstruction, which directly impacts the future resiliency of the community. In order to decrease the timeframe between the disaster, emergency response, the relief phase, and the recovery of the community, a new building assembly system must be developed to solve this problem.

DESIGN FOR DISASTER DISPLACEMENT

By

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Chapter 1: Introduction

Natural disasters continue to occur at increasing rates as the world's climate changes due to human induced factors. However, many regions are unprepared or unaware of the risks of possible hazards, including earthquakes. A lack of preparedness includes limited plans for the relief and recovery phases, building codes and regulations lacking in related structural constraints, and a population of individuals who have no knowledge of the possibility of the occurrence of a seismic event. In particular, it is especially perilous to regions that are high in density but with mild seismic risk. This combination of unpreparedness and lack of awareness coupled with a dense population is an equation for a catastrophic disaster. Therefore, a plan for relief, recovery, and reconstruction is required to allow for a fluid transition back to normalcy. Since many human behaviors occur within the built environment, it is essential to provide a plan to rapidly construct structures to house displaced populations until their homes are restored. This design opportunity can be used to develop a system of construction to assist the process of recovery.

While replacing infrastructure and updating buildings to be shock resistant is quite invasive and expensive, there can be changes in the way society addresses the effects that can be controlled. The continual displacement of people is unacceptable and makes the return to normalcy more difficult. If design can smooth this transition between housing alternatives, it would create a more settling environment for the affected communities. It is essential to understand the relationship between the cause, the disaster, and the effects in order to ensure that the responses are effective and efficient in their design

Chapter 2: Natural Disasters

What are disasters

Natural disasters can take many forms, including earthquakes, hurricanes, tsunamis, and tornadoes. Although it appears they are mutually exclusive, there are typically correlations between these separate events.

What is causing them

There are certain factors that are particularly responsible for causing natural disasters. As humans affect the planet due to pollution and the misuse of natural resources, the climate of the earth is being altered. Climate change has not created natural disasters, but rather has caused the increase of occurrences. Climate change is also affected by rapid urbanization, in which humans are rapidly increasing the industrial capacity of cities and the demands on the available resources.[1] With growing populations and infrastructures, the world' exposure to hazards, both natural and manmade, is increasing.

In order to identify an occurrence as a natural disaster, humans must be affected, either through dense population, the effects on an economic epicenter, or damage to infrastructure. During the last century, natural disasters have become a common event throughout the world, affecting both developing countries and developed countries. Natural disasters do not discriminate; they affect populations of

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[1] Mary C. Comerio, *Disaster Hits Home: New Policy for Urban Housing Recovery* (Berkeley: University of California Press, 1998), 26.

varying densities and economic situations. Nonetheless, it is important to identify what a disaster is. If an earthquake hits a deserted island, it is not considered a disaster. It is, in fact, the effects on humans that qualify it as a disaster. Without the destruction of the built environment, the damaging of infrastructure, and physical harm inflicted on people, an earthquake would simply be considered part of the natural cycles of the earth.[2] This reality will undeniably require a frequent reconstruction of communities, both physically and socially, while protecting people and their environment to ensure those communities are less vulnerable in the future.

What are the effects

Aside from the expected building damage, there are other consequences that occur due to seismic activity. As natural disasters occur in an unexpected fashion, there are physical and social effects throughout the aftermath. Often, there are natural effects that occur following the initial disaster, which can include aftershock tremors, storm surge, and flooding. Sometimes after earthquakes, fires can break out and sometimes "surpass the total losses from collapse of buildings and disruption of lifelines".[3] It has been estimated that following larger seismic events, hundreds of fires could break out simultaneously, resulting in a situation that surpasses the current firefighting capacity. As infrastructure is damaged, utility outages occur and residents

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[2] Ibid., 48.

[3] "Earthquake Loss Estimation Study for The New York City Area (NYCEM 1st -Year Technical Report)," 9, accessed November 26, 2013, http://www.nycem.org/techdocs/lossEstYr1/.

are left without electricity. This causes a rift in communication and a level of comfort, particularly if the natural disaster occurs during winter or summer. There is also often pollution of water sources, which can contribute to the spread of disease as well as discomfort and related health issues.[4] Damaged infrastructure can limit the amount of accessibility to a site and therefore, a lack of medical attention can become a problem for affected residents. Destruction of buildings can be extremely detrimental and cause human injury and even death. This destruction leaves a trail of rubble and debris, which must be cleared as quickly as possible in order to provide transportation access. The debris that is likely to be generated due to a magnitude 5 earthquake could be comparable to that of the 9/11 tragedy, up to 1.6 million tons.[5] Debris of this scale would require almost 10,000 times the daily trash hauling capacity.[6]

While these physical changes are daunting to tackle and clean up, there are also underlying effects on the community. As populations typically need to be displaced and transported to emergency shelter, this process is often unsettling and disruptive to their typical social interactions. This also negatively impacts the economy of the culture, which can lead to long term consequences. The level and quality of "pre-disaster planning will largely determine the post-disaster response;

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[4] "The Disaster Management Cycle," accessed November 26, 2013, http://www.gdrc.org/uem/disasters/1-dm_cycle.html.

[5] "Earthquake Loss Estimation Study for The New York City Area (NYCEM 1st - Year Technical Report)," 9.

[6] Ibid.

and, the effectiveness of post-disaster reconstruction will determine to what extent the community remains vulnerable to the threats posed by hazards in the future, defined as ‘sustainable hazard mitigation’.[7]

It is evident that there is an important link between the physical requirements of the built environment with the broader social, natural, institutional and economic needs of the community. The built environment serves many human endeavors, so when elements of it are damaged or destroyed, it severely disrupts the ability of society to function. Because each community is different, it is impossible to apply generic solutions, such as prototypical emergency housing, and expect them to provide residents with all of the needs of housing. Therefore, designers must assist with the pre-disaster preparedness planning in order to maximize benefits during the “window of opportunity” following a natural disaster.

What happens after a disaster

Emergency Response

To better understand the response process, it must be broken down into components depending on their function, including emergency response, relief phase, and recovery phase. The emergency response is the initial reaction to a natural disaster, which usually occurs within 24 hours of the disaster and can continue for as long as a few weeks, depending on how prepared the region and organizations are.[8]

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[7] *Post-Disaster Reconstruction of the Built Environment: Rebuilding for Resilience* (Chichester, West Sussex, UK ; Ames, Iowa: Wiley-Blackwell, 2011), 3.

[8] “The Disaster Management Cycle.”

Some main elements of this phase include fire suppression, flood control, and the cleanup of hazardous materials to initially combat immediate dangers. The next series of events include emergency medical response, stabilization of structures, and emergency housing, which typically includes cots within a public structure.[9] While providing a safe, comfortable place for people to be housed, it is not ideal.

Relief Phase

The second phase can begin as soon as a few days following the disaster but could be delayed for months or years, depending on the severity of the damages. External aid begins to arrive to provide both financial and physical assistance to the affected communities.[10] During these months, organizations work to clear the debris and restore normal public services. There is also an assessment of the damage by insurance companies to determine the amount of money and time that will be required to rebuild.[11] In this relief phase, temporary housing is typically provided to the displaced population.

Recovery Phase

In the recovery phase, the final step toward normalcy, which may take place from months to years after the disaster. Depending on the disaster and how much damage was incurred, this phase could span, in the most extreme cases, twenty years until the community experiences normalcy again. While teams assemble to repair and

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[9] Ibid.

[10] Ibid.

[11] Ibid.

replace damaged buildings, residents begin to move back into their homes, hoping another natural disaster will not destroy their homes again. The goal of this thesis is to design a system to encourage other resilient, context sensitive buildings that will reduce hazard vulnerability and enable society to continue functioning economically and socially when subjected to a natural disaster.

How can recovery be more compressed

By analyzing the current timeline of recovery following a natural disaster, a new process can be designed to create a more compressed and streamline series of interventions. Instead of completing the emergency response, then the relief phase, followed by the recovery phase, there can be a more seamless transition by creating an intervention that can evolve between all phases. This can be addressed through a redesign of our construction systems. If a process can be developed to rapidly fabricate, transport, and erect a structure, the time lapse between the emergency response, the relief phase and the final recovery can happen during a compressed amount of time. In order to accomplish this, it is imperative to be creative how to edit certain building regulations in order to develop an innovative method to address this problem.

Figure 1: Typical Recovery Phases

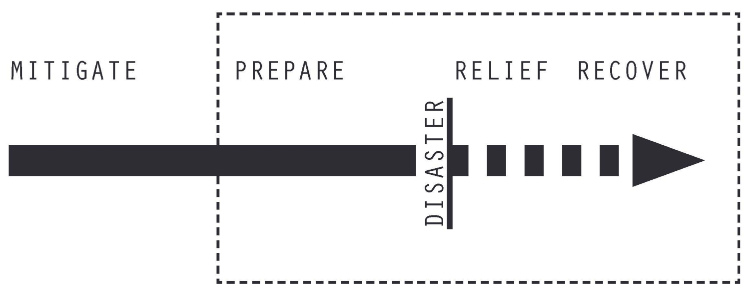

Figure 2: Compressed Recovery Phases

<u>*What organizations are involved*</u>

In general, the Federal Emergency Management Agency (FEMA) organizes partnerships between other government agencies, including The US Department of Agriculture (USDA), the Department of Veteran Affairs (VA), and the Department of

Housing and Urban Development (HUD) to “meet the challenge of finding and securing sufficient rental assets to meet the huge demands created by mass evacuations”.[12] Specialty agencies are typically formed for the specific disaster, as well.

[12] “Failure Initiative,” 314, accessed November 26, 2013, http://govinfo.library.unt.edu/katrina/shelterandhousing.pdf.

Chapter 3: Role of Housing

Why is housing important to restore

When one thinks of their normal daily activities, one may describe waking up, going to work, and ending up at home again before going to sleep. By analyzing the amount of household activities, one can begin to understand why the home is an essential part of life.

By using the data from the American Time Use Survey, it is evident that about 16 hours of the average adult's day is spent at home.[13] A home occupies a special place in the hearts of individuals and becomes a physical symbol of family. When one does not have the comforts of home, it can be difficult to continue with other aspects of life, such as a career or other activities. Particularly on the East coast, there is extreme density in the housing is due to the large amount of urban areas throughout the region

[13] Ibid.

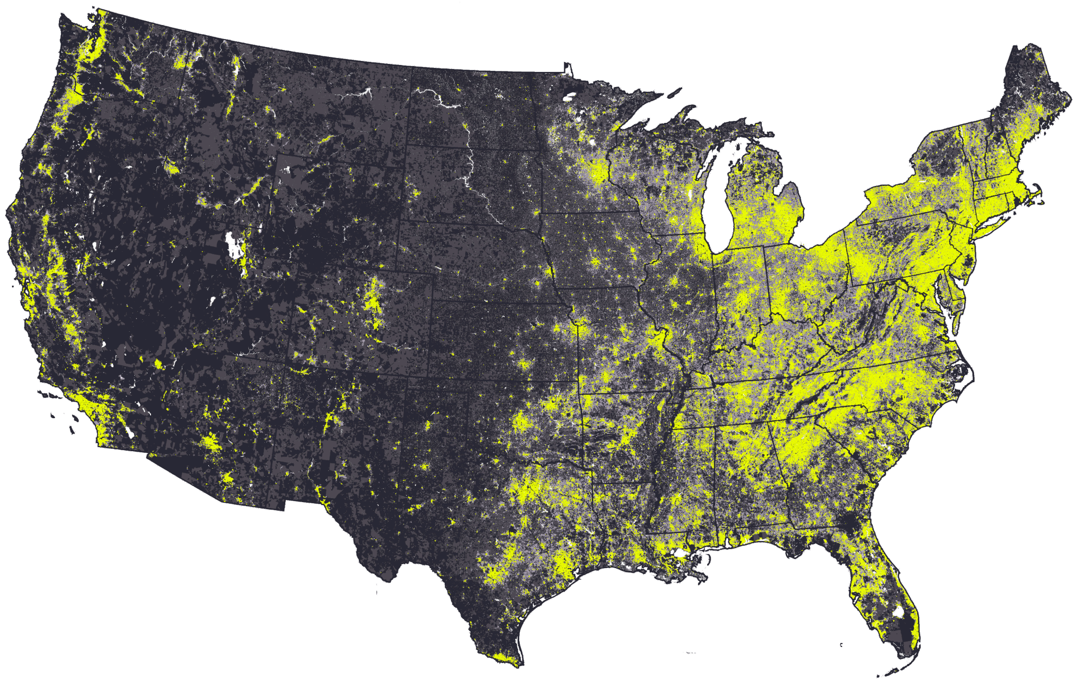

Figure 3: Housing Density in United States

How is it affected by disasters

Today, many emergency response shelters are made up of tent structures, prefabricated mobile homes, or conversion of existing, stable buildings. While these options are affordable and relatively rapidly deployable, they present further issues. Like food and water, shelter is a basic human need; however, following a natural disaster, residents are displaced and are typically relocated to inadequate shelters. Housing must provide protection from the elements, in addition to preserving a sense of dignity, orientation, and identity. The options currently available may provide protection from the elements, but the other components are ignored, since they are typically considered unnecessary. However, it is these additional components that make the displacement of individuals and families less of a transition. If they are able to fully live their lives, while continuing working and attending school, they will be less affected by the aftermath of a disaster. Therefore, the built environment is able to control and mitigate the consequences of a natural disaster if it is properly designed, constructed, and arranged.

Hurricane Katrina as case study

Using Hurricane Katrina as a study, it is evident that the "relocation plans did not adequately provide for shelter".[14] After Hurricane Katrina hit land in 2005, it displaced over one million people and 80% of the City of New Orleans was under water.[15] Displaced populations were housed in "emergency shelters, including large congregate shelters, cruise ships, hotels, and rental apartments".[16] FEMA also requested 150,000 trailers in September 2005, each costing $59,150 for 18 months.[17] This quantity surpassed the manufacturing capabilities of the United States and did not provide any permanent reconstruction. The most serious problem caused by these

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14 "Failure Initiative," 312.

15 "FEMA," 1, accessed November 26, 2013, https://www.llis.dhs.gov/sites/default/files/DisasterHousingInves.pdf.

16 Ibid., 3.

17 Ibid., 8.

trailers was the health risks associated with the formaldehyde used in the structures.[18] Although the mobile homes were “the fastest means of adding to the local housing stock, [using] mobile homes as a strictly temporary housing solution diverts vital construction resources, money and time… while doing little to move the community to permanent recovery”.[19] There were also problems with water, sewage, debris removal, schools, and government facilities are attributed to FEMA’s lack of preparedness.[20] In summary, there were eight fundamental problems underlying FEMA’s post-Katrina response:

1. “ FEMA had no operational catastrophic disaster plan
2. FEMA’s programs were insufficient to meet housing needs in post-catastrophic events
3. FEMA decisions to reject options resulted in heavy reliance on costly trailers and mobile homes
4. Legal interpretations eliminated housing options
5. FEMA’s programs were marked by frequent changes and errors
6. FEMA had insufficient and poorly trained staff
7. The needs of the renters were not met

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[18] Ibid., 9.

[19] Ibid., 236.

[20] Ibid., 11.

8. Flawed FEMA public assistance programs blocked State and local governments from restoring public services needed for housing recovery”.[21]

If such a catastrophic event were to occur again, many evacuees may be displaced for a longer than normal period of time or may permanently lose their housing. In general, “evacuees tend to go to the most convenient and familiar shelter they can find, even though it may be inadequate”.[22] Therefore, it is important that there are many emergency housing sites abundantly available so they can be located in close proximity to those in need. Basic shelter should be provided so that individuals and families can focus on finding jobs and obtaining permanent housing. Many families were forced to live outside of a reasonable commuting distance of their pre-disaster jobs, thus delaying the return to normalcy.[23] FEMA advocates “improved shelter planning to address the full range of disasters, including catastrophic events and a national planning effort must be undertaken to address sheltering in the aftermath of catastrophic events”.[24] FEMA has outlined program funding, efficiency, cost effectiveness, and population served as their key considerations for future interventions.[25] After Hurricane Katrina, improvements to the relief system have been

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[21] Ibid., 12.

[22] “Failure Initiative,” 313.

[23] “FEMA,” 263.

[24] Ibid., 254.

[25] Ibid., 259.

proposed. One of them includes “developing more detailed concepts and plans on sheltering and temporary housing”.[26]

What innovative responses are being researched

Many designers have begun to utilize certain design principles, such as modularity, flat packing capabilities, prefabrication, and utilization of local available materials. These innovative concepts of building construction and transportability will be useful as precedents to study when designing the disaster recovery community.

IKEA

IKEA has participated in the efforts to develop an improved system for disaster relief housing. This flat pack house is easy to transport, can be built in just four hours, and can sleep five people comfortably.[27] It is designed to be twice the size of the required size of a refugee tent, 100 square feet. The structure comes fully equipped with “solar powered roofing, eliminating the need for candles or lamps,

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[26] “Failure Initiative,” 312.

[27] “8 Innovative Emergency Shelters for When Disaster Strikes IKEA Refugee Shelter - Gallery Page 2 – Inhabitat - Sustainable Design Innovation, Eco Architecture, Green Building,” accessed November 26, 2013, http://inhabitat.com/8-innovative-emergency-shelter-designs-for-when-disaster-hits/ikea-refugee-shelter2-2/?extend=1.

which can cause fire" while the "roof deflects solar heat gain by 70%, keeping the interior habitable during hot weather".[28]

EDV-01 Emergency Shelter

The EDV-01 Emergency Shelter by Daiwa Lease ships in the size of a shipping container, but once deployed, expands to double the height by a hydraulic system.[29] A hydraulic system uses a force that is applied at one point that is transmitted to another point using an incompressible fluid. This force jacks up the second level of the structure. The structure can "sustain itself without any outside resources for up to a month by catching and reusing water and generating electricity with a sizable solar array".[30] It also provides a bunk bed, a desk, a shower, bio toilet, a small kitchen and storage space. Utilities that are immediately available can provide for a healthier and higher quality living experience.

The AbleNook

The AbleNook was designed by graduate students at the University of South Florida. It is a prefab module that can be attached to another module to expand the unit.[31] The parts are flat-packed for shipping and can be assembled in two hours. The design is based on "identical and universal aluminum structural insulated panels (SIPS) that

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[28] Ibid.

[29] Ibid.

[30] Ibid.

[31] Ibid.

clip together without the use of any tools".[32] The joists and columns are also identical and are equipped with electrical conduit to allow easy plug-and-play assembly.

Shigeru Ban

Shigeru Ban has become known for his disaster relief projects, in particular designs that utilize paper as the main material. This innovative use of affordable, yet durable, materials allows for the design to be used anywhere in the world. More specifically, he creates paper tubes to act as the structure for projects of any scale, from paper partitions that provide a sense of privacy in public shelters to a cathedral type space for a disaster stricken community.[33]

Architecture for Humanity

Architecture for Humanity is a nonprofit design services firm that provides professional design to areas in need. The Reconstruction and Resiliency Studio team works with communities on projects related to resiliency, long term recovery and post-disaster reconstruction. The firm has participated in the recovery of the Earthquake in Haiti, Hurricane Sandy, Hurricane Katrina, and many others.[34]

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[32] Ibid.

[33] "Works | Shigeru Ban Architects," accessed November 26, 2013, http://www.shigerubanarchitects.com/works.html.

[34] "Reconstruction & Resiliency Studio | Architecture for Humanity," accessed November 26, 2013, http://architectureforhumanity.org/studio/reconstruction-and-resiliency.

Competitions

Competitions act as generators for innovative ideas that otherwise might be deemed impractical. One competition in particular, What if New York City, has intriguing finalist projects that introduce provocative new ideas to be explored in disaster relief projects. In particular, the project S.C.A.L.E., sustainable contemporary adaptive living environment, traces the life cycle of the temporary structure.[35] The project addresses the deployment, as "scissor containers" arrive at the site, which become expanded on site, then can be easily deconstruction and shipped off site to be stored. The system is compressed to be transported in the size of a shipping container, but then expands on site to become three stories high, which helps to accommodate a greater density of people.[36] These precedent studies begin to demonstrate some of the inventive processes and materials that can be explored to redevelop disaster relief housing.

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[35] "What If New York City...Design Competition for Post-Disaster Provisional Housing," accessed November 26, 2013, http://www.whatifnyc.net/.

[36] Ibid.

Chapter 3: Earthquakes

What can we learn from the past?

Damage by Earthquakes

Direct disaster aspects by earthquakes include loss of housing, loss of business production, loss of industrial production, damages to infrastructure, disruption of transport, and disruption of communication. Typically, earthquakes tend to impact infrastructure and large buildings most. However, after studies of previous earthquakes, it is understood that the housing stock is also significantly affected.

Single Family	71%	40%	63%	11%
Multifamily	11%	60%	29%	88%
Mobile Homes	18%	0%	8%	>1%
Uninhabitable	32%	25%	59%	13%
Value Residential Losses (Billions)	$3	$2	$15.5	$12.7
Residential Insurance Paid (Billions)	$1.5	$0.57	$10 .8	$7.8
# Insurance Claims Paid	278,000	45,000	316,000	265,000
Value of Public Assistance for Housing (Billions)	$0.5	$0.6	$1.2	$4.7
Vacancy Rate	8%	<1%	10%	9%
Concentration	25% Berkeley, Charleston, Dorchester, Sumter Counties	>1% Oakland/ San Francisco; 10% Watsonville/ Santa Cruz	6% South Dade County	3% San Fernando Valley (1.5% of Los Angeles)
Recovery	90% in 1 year	Single family: 90% in 1 year; multifamily: 50% in 7 years	75% in 2 years, limited rebuilding of multifamily	80% in 2 years; 20% without financing

SOURCE: See chapter 2 of this book.

Figure 4: Damage to Housing Stock in Previous Earthquakes[37]

By analyzing the Loma Prieta earthquake in 1989, 11,500 housing units were destroyed or incurred major damage. Although less than 1% of the population was displaced, those families were placed in temporary housing solutions. Within one

[37] Comerio, *Disaster Hits Home*, 171.

year, 90% of the single family homes were considered habitable after repairs, while it took 7 years for 50% of the multifamily housing stock to be restored due to greater damage.[38]

The Northridge earthquake of 1994 also caused massive damage to single family and multifamily residential units. 60,000 units were destroyed or incurred major damage, 11% were single family homes and 88% were multifamily units.[39] This caused a 9% displacement rate and $7.8 billion of residential insurance was paid. The recovery restored 80% of the damaged housing within two years. This is considered a rather quick recovery time frame, while some earthquakes create larger disruption to the housing stock in particular.[40] However, two years in temporary or transitional housing is socially disruptive and difficult on the families in need. If a process can be found that provides a stable and culturally fitting housing alternative, it would be much preferred.

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[38] Ibid., 171.

[39] Ibid.

[40] Ibid.

Chapter 4: Seismic Design

What are the four principles of good seismic design

It is important that the disaster recovery community is designed to resist future earthquakes. In addition, this development will act as an example of design innovation and will encourage other buildings to take these building principles into consideration.

For buildings to perform during seismic activity, they must possess the following four principles. Buildings should be able to withstand this imposed deformation with no or limited damage under small intensity shaking with no collapse under high intensity shaking.[41] Firstly, good seismic configuration is essential to controlling the building behavior during an earthquake. Complexities in design should not be introduced to the overall geometry. Secondly, lateral stiffness should be uniformly distributed across the plan to minimize damage to the building and discomfort to the occupants. Thirdly, lateral strength uniformly distributed across the plan is necessary to be designed with vertical strength to support the gravity load and prevent collapse under strong seismic shaking. Lastly, good overall ductility should be provided to act against the imposed lateral deformation between the base and the roof of the building.[42] These four principles should be integrated into the structure's

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[41] "Microsoft Word - EBB_01_FrontCover_30May2013.doc - EBB_001_30May2013.pdf," 10, accessed November 26, 2013, http://www.iitk.ac.in/nicee/IITK-GSDMA/EBB_001_30May2013.pdf.

[42] Ibid.

design to ensure optimal building performance during seismic activity. In order to achieve these design principles, it is imperative to integrate them into the building's planning, design, construction, and maintenance.

How do buildings react during seismic activity

The general theory to explain building activity during a seismic event is Newton's Second Law of Motion, F=ma. From this equation, a more specific equation, V= CsW, was developed, where V is the seismic base shear, Cs is the seismic design coefficient, and W is the weight of the structure. In order to design a building that can withstand seismic activity, one can either reduce demand, which is increasing the ductility of the structure, or one can increase capacity, which is overdesigning the structure of the building.

During an earthquake, buildings will oscillate during the earthquake shaking, and the oscillation causes inertia forces throughout the building. There are three general modes of oscillation, including translation along X-axis, translation along Y-axis, and rotation about Z-axis.[43] The combination of modes depends on the general geometry of the building, geometric and material properties of structural members, and connections between the structural members and the ground at the base of the building. Factors that affect these mode shapes include flexural stiffness of structural elements, axial stiffness of vertical members, degree of fixity at member ends, and building height.[44]

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[43] Ibid., 32.

[44] Ibid., 39.

The amount of oscillation and inertia forces are dependent on the features of the building, defined as their dynamic characteristics. The natural period of a building is "the time taken by it to undergo one complete cycle of oscillation" which is dependent on its mass and stiffness.[45] Buildings that are more massive and less stiff have larger natural periods than light and stiff buildings. This understanding will provide a framework in which the disaster recovery community should be designed. All of these concepts considered, height, stiffness, structural system, plan configuration, and ductility, all contribute to the building's resistance to future seismic activity, also acting as an example of good building practice for other developments.

Using a study of 10 buildings of various proportions, conclusions can be drawn about the most effective building layouts.

Table 2.5: *Buildings considered to illustrate concept of natural period*: Details of 10 buildings considered

Building	*Description*	*Number of Storeys*	*Number of Bays*		*Column Dimension (mm × mm)*
			X-direction	*Y-direction*	
A	2 storey building	2	4	3	400 × 400
B	Benchmark 5-storey building	5	4	3	400 × 400
C	Benchmark building with rectangular columns oriented along X direction	5	4	3	550 × 300
D	Benchmark building with rectangular columns oriented along Y direction	5	4	3	300 × 550
E	10-storey building with varying column size along building height	10	4	3	Upper 5 storeys: 400 × 400 Bottom 5 storeys: 600 × 600
F	10-storey building	10	4	3	600 × 600
G	25-storey building with varying column size along building height	25	4	3	Upper 5 storeys: 400 × 400 Middle 10 storeys: 600 × 600 Bottom 10 storeys: 800 × 800
H	25-storey building	25	4	3	800 × 800
J	25-storey building with imposed mass 10% larger than building H	25	4	3	800 × 800
K	25-storey building with imposed mass 20% larger than building H	25	4	3	800 × 800

Note
1. Bay length in each plan direction is 4m (center to center).
2. All columns at each storey are of the same size.
3. All beams in all buildings are of the same size (300mm × 400mm)

Figure 5: Buildings to Illustrate Natural Period[46]

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[45] Ibid., 18.

[46] Ibid., 21.

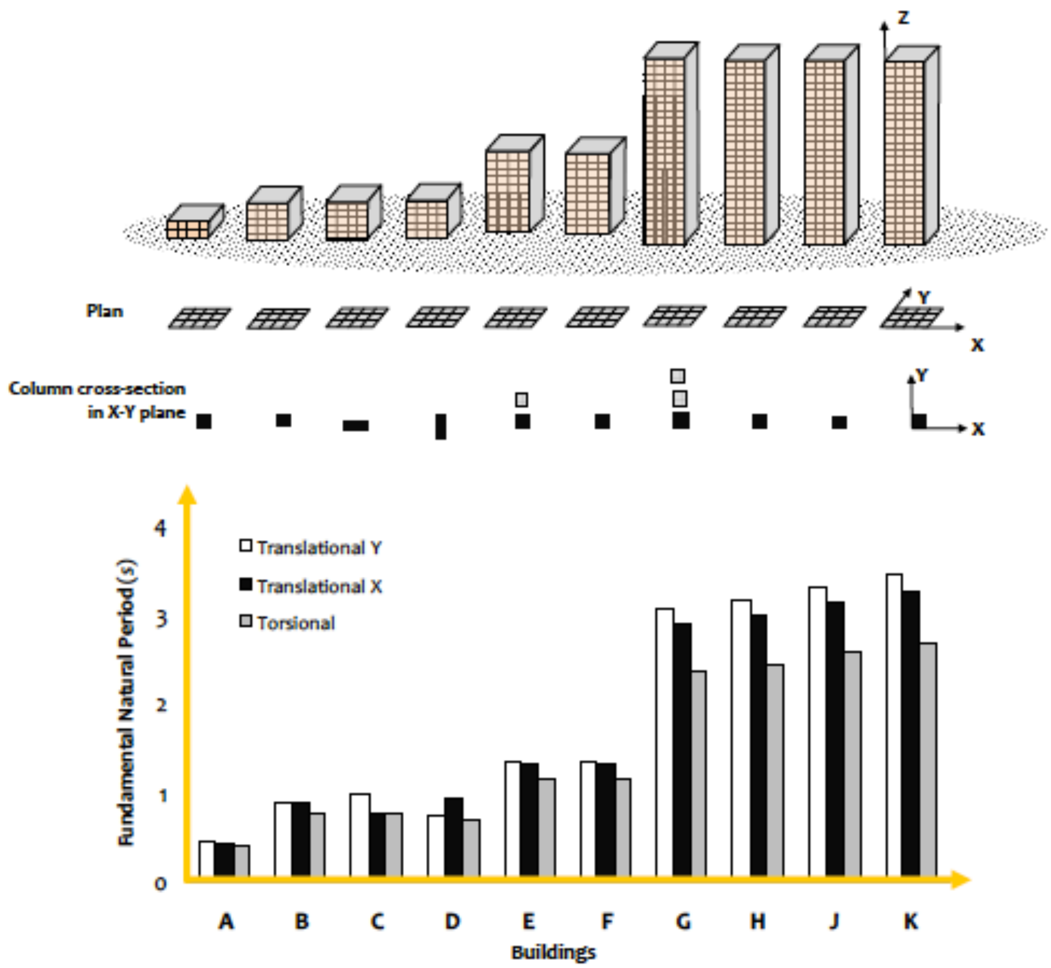

Figure 2.14: *Summary of natural periods of buildings considered*: Natural periods are influenced by mass and stiffness parameters of buildings

Figure 6: Summary of Natural Periods of Buildings[47]

In summary, there are major trends that can be identified:

“1. Natural periods of buildings reduce with increase in stiffness.

2. Natural periods of building increase with increase in mass.

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[47] Ibid., 28.

3. Taller buildings have larger fundamental translational natural periods.
4. Buildings tend to oscillate in the directions in which they are most flexible and have larger translational natural periods.
5. Natural periods of buildings depend on amount and extent of spatial distribution of unreinforced masonry infill walls".[48]

What components to consider

Configuration

Configuration is the firststep to good seismic performance of buildings. These elements include the overall geometry, structural systems, and load paths. Firstly, the overall geometry include elements such as the plan shape, the plan aspect ratio and the slenderness ratio of the building. Buildings with a basic convex plan shape have direct load paths for transferring seismic inertia forces to its base, while those with concave plans shapes create indirect load paths that result in stress concentrations at points where load paths bend.[49] Designing with a simple or convex plan can be analyzed through studying different plan configurations and their behavior during seismic behavior.

[48] Ibid., 27.

[49] Ibid., 53.

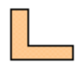
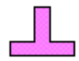
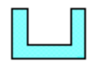
Mode	*Type of oscillation in first six modes in buildings with different plan shapes*					
						
1	Y-translation	Y-translation with torsion	X-translation	*Torsion*	X-translation with torsion	*Torsion*
2	X-translation	X-translation with torsion	Y-translation	Y-translation	Y-translation with torsion	X-translation
3	*Torsion*	*Torsion*	*Torsion*	X-translation	Torsional	Y-translation
4	Opening-closing	Opening-closing	Opening-closing	Opening-closing	Opening-closing	Dog tail wagging
5	Mixed	Dog tail wagging	Mixed	Mixed	Dog tail wagging	Opening-closing
6	Mixed	Mixed	2nd X-translation	Mixed	Mixed	Mixed
Note: Diagonal translation, torsion, opening-closing, and dog-tail-wagging are not acceptable as initial modes of oscillation in buildings						

Figure 7: Type of Oscillation by Building Form[50]

Building made up of complex plans with projections are more susceptible to special modes of oscillation, in addition to translator or torsional modes, and create stress concentrations at their corners. Projections, if required, should be short rather than long to reduce concentrations of stress.

In summary, the major trends that can be identified are:

"1. Torsional modes of oscillations are predominant in buildings with L, X, and Y plan shapes, which should be avoided with suitable choice of structural configuration;

2. Diagonal translation modes of oscillations are predominant in buildings with L and X plan shapes, which should be avoided with suitable changes in structural configuration;

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[50] Ibid., 57.

3. Opening-closing and dog-tail-wagging modes of oscillation cause significant stress concentrations at re-entrant corners and can cause structural damage;

4. It is prudent to not use buildings with complex plan shapes, or if compelled, ensure that their natural periods are small".[51]

It is also important to design buildings with a small plan aspect ratio. Through research, it has been identified that when the aspect ratio increases, the in-plane deformation increases.

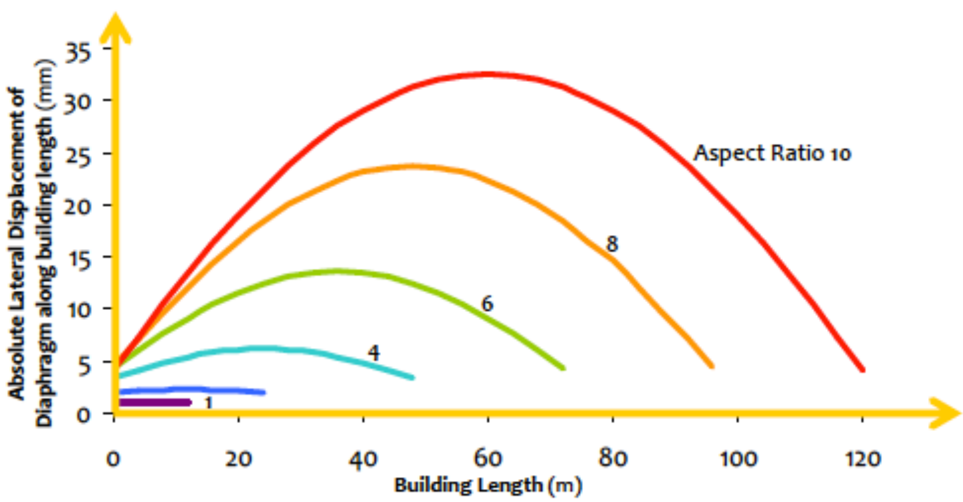

Figure 8: Lateral displacement of Buildings due to Aspect Ratio[52]

[51] Ibid., 69.

[52] Ibid., 72.

Almost rigid diaphragm action is realized in buildings with a plan aspect ratio of 4 or less, so it is important to design within this range.[53]

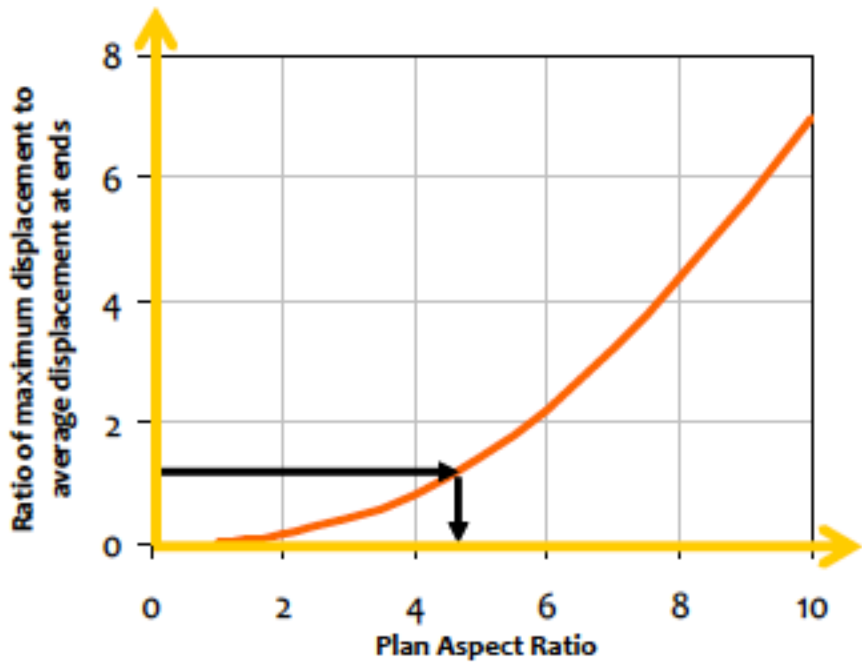

Figure 9: Maximum Displacement in Relation to Plan Aspect Ratio[54]

In-plane deformation depends on both the distribution of lateral stiffness of vertical elements in plan and the distribution of mass of the building in plan. In addition, in-plane deformation of the diaphragm increases with cut-outs, while the deformation decreases with a greater number of well distributed structural walls along the length of the building.[55] The proportion of cut-outs in the diaphragm has a direct effect its

[53] Ibid., 72.

[54] Ibid., 72.

[55] Ibid., 74.

displacement during seismic activity. Because of this, it is important to restrict the maximum diaphragm opening to 50% of the overall area.[56]

In terms of a building's slenderness ratio, it is preferred to design with a small slenderness ratio. This helps to reduce the amount of lateral displacement, which is undesirable behavior. Lateral displacement can cause significant structural damage, which can lead to the collapse of buildings.[57] In addition, limiting the height of the building will also reduce the amount of lateral deformation.

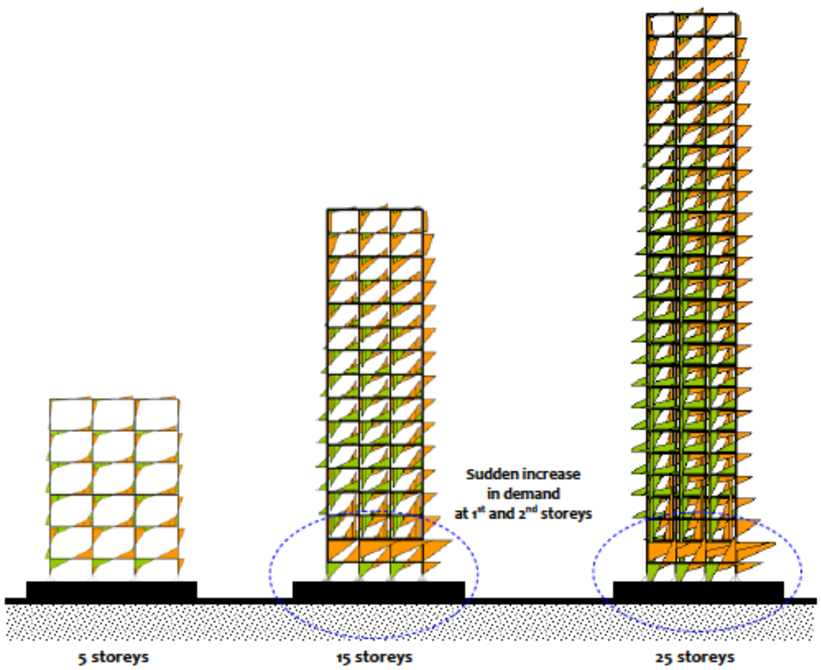

Figure 10: Effect of Slenderness Ratio[58]

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[56] Ibid., 79.

[57] Ibid., 81.

[58] Ibid., 83.

Structural Systems

The structural system is also essential for good seismic performance of buildings. Some of the most common systems to resist lateral load include moment-frame, structural walls, frame-wall system and braced-frame system.

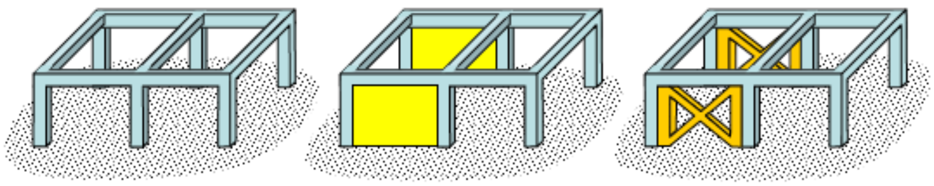

Figure 11: Common Structural Systems[59]

Braced frame systems can be provided in both plan directions and throughout the height of the building to help in reducing overall lateral displacement of building and in reducing the bending moment and shear force demands on beams and columns.[60] While looking at the same building with X bracing, chevron bracing, and K bracing, it is clear that X and chevron braces help reduce moment and shear demand on columns and beams, while K braces do not.

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[59] Ibid., 84.

[60] Ibid., 99.

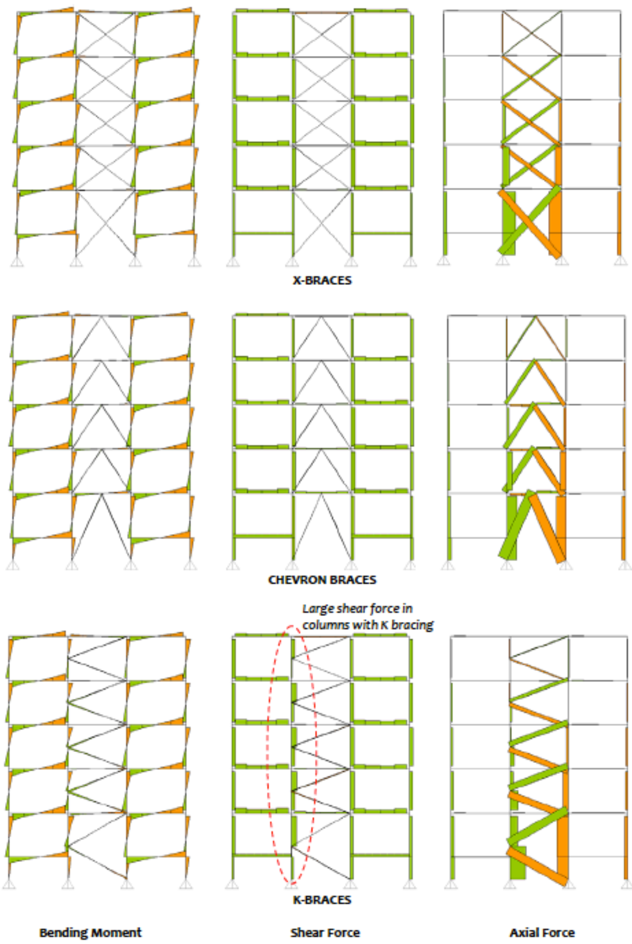

Figure 12: Bracing and Distributed Forces[61]

It is important to decrease the amount of discontinuity in the load path, which can occur due to set-back columns. When the forces have to change paths, it can cause severe stress concentration at the corners while travelling to the next set of columns.[62] This can also occur due to a lack of grid in the moment frame, which can cause

[61] Ibid., 88.

[62] Ibid., 124.

torsion of the building and increase shear in short span. It can result in localized failure than can in turn trigger global collapse of the building.[63]

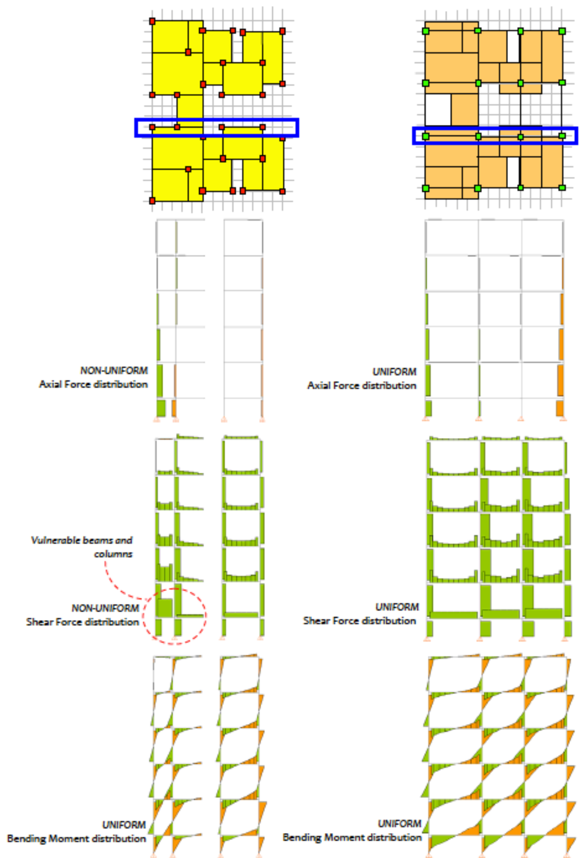

Figure 13: Forces Acting on Building[64]

In general, irregularity in the overall geometry of a building can affect its behavior during earthquakes. When considering set-back or step back buildings, it is important to note that they "typically result in concave geometries that have a number of re-entrant corners at which load paths are disturbed requiring sharp bends".[65]

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[63] Ibid., 126.

[64] Ibid., 127.

[65] Ibid., 155.

Mass

In terms of the mass of a building, "inertia forces are generated in buildings during earthquake shaking at locations where masses are present".[66] In order to mitigate this, the mass of a building must be distributed uniformly. Unevenly distributing masses in plan, such as water tanks, can cause translational movement and torsion. Mass irregularity can also occur in elevation, such as a heavy story located on an upper level, can cause torsion as well.

The adjacency of buildings is often overlooked as a cause of structural damage during seismic activity. A minimum design distance must be employed to avoid pounding of two adjacent buildings. A singular building can also be divided by the use of seismic joints to facilitate better behavior, as opposed to expansion joints that are made for thermal considerations.[67] The three most fatal arrangements of buildings include two buildings directly adjacent to each other of the same height, of different story heights or of different overall heights.

[66] Ibid., 134.

[67] Ibid., 161.

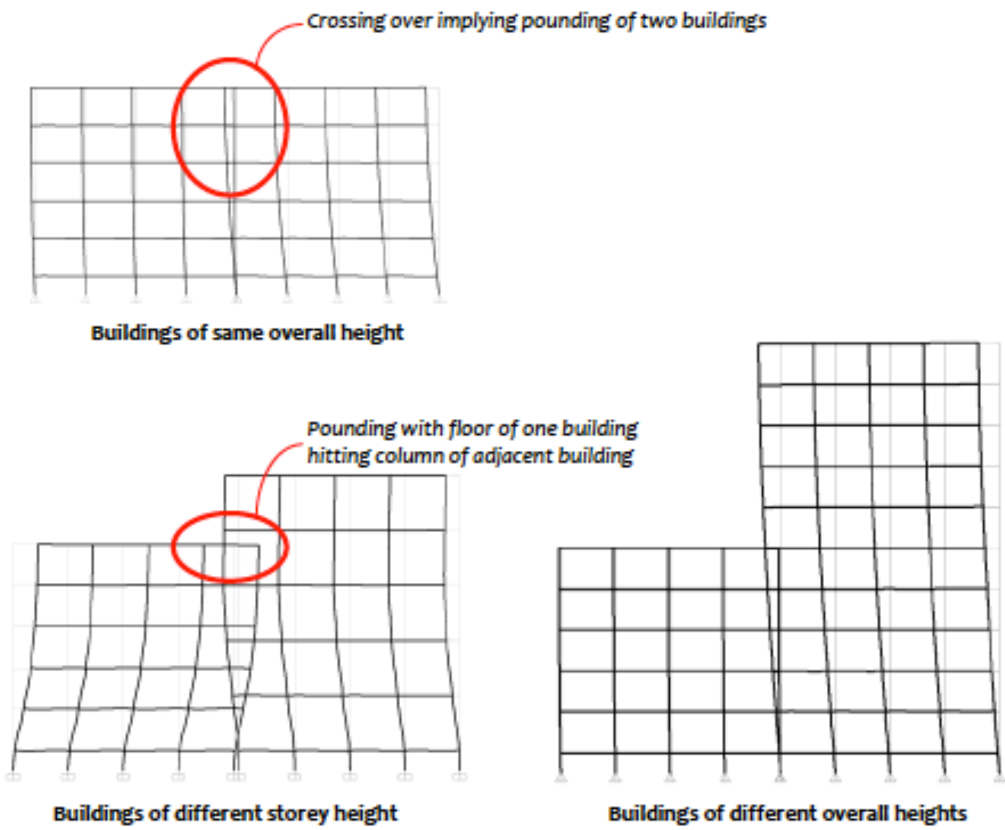

Figure 14: Adjacency of Buildings[68]

This pounding should be avoided by providing adequate separation, typically three times the estimated possible displacement. This allows for a margin depending on the seismic event.

Foundations

The soil flexibility of the site must also be considered when designing the foundation system. The three basic types of foundations that are commonly used are

[68] Ibid., 165.

isolated footings, raft foundation, and pile foundation.

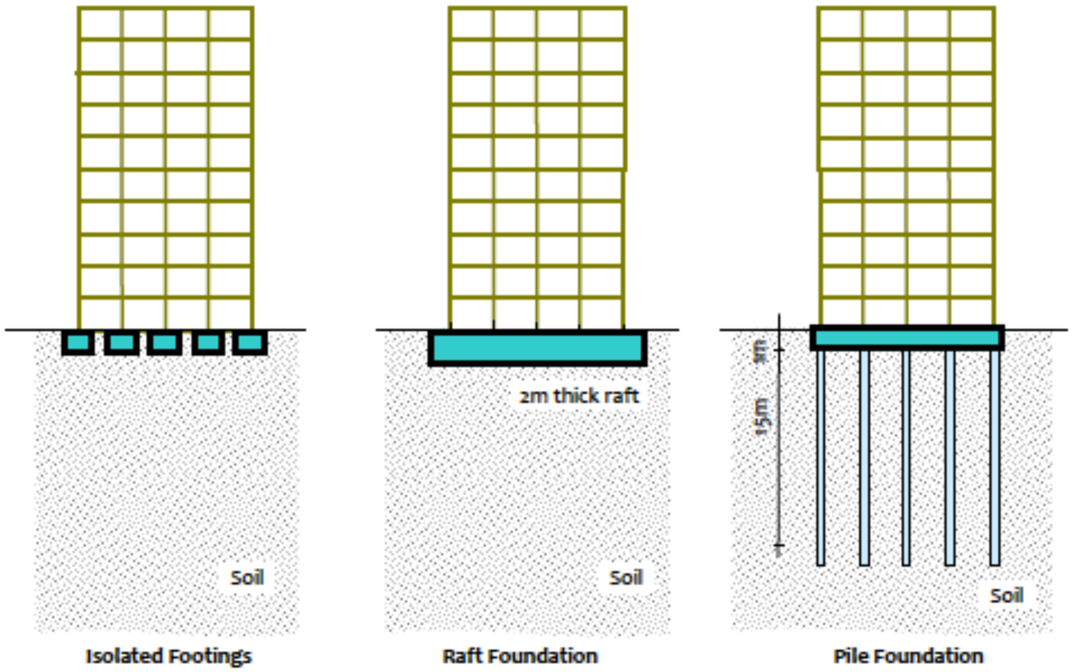

Figure 15: Different Foundation Options[69]

[69] Ibid., 168.

When analyzing which foundation type would function best in stiff soil/rock, it is evident that the soil is a considerable influence in all three cases.[70]

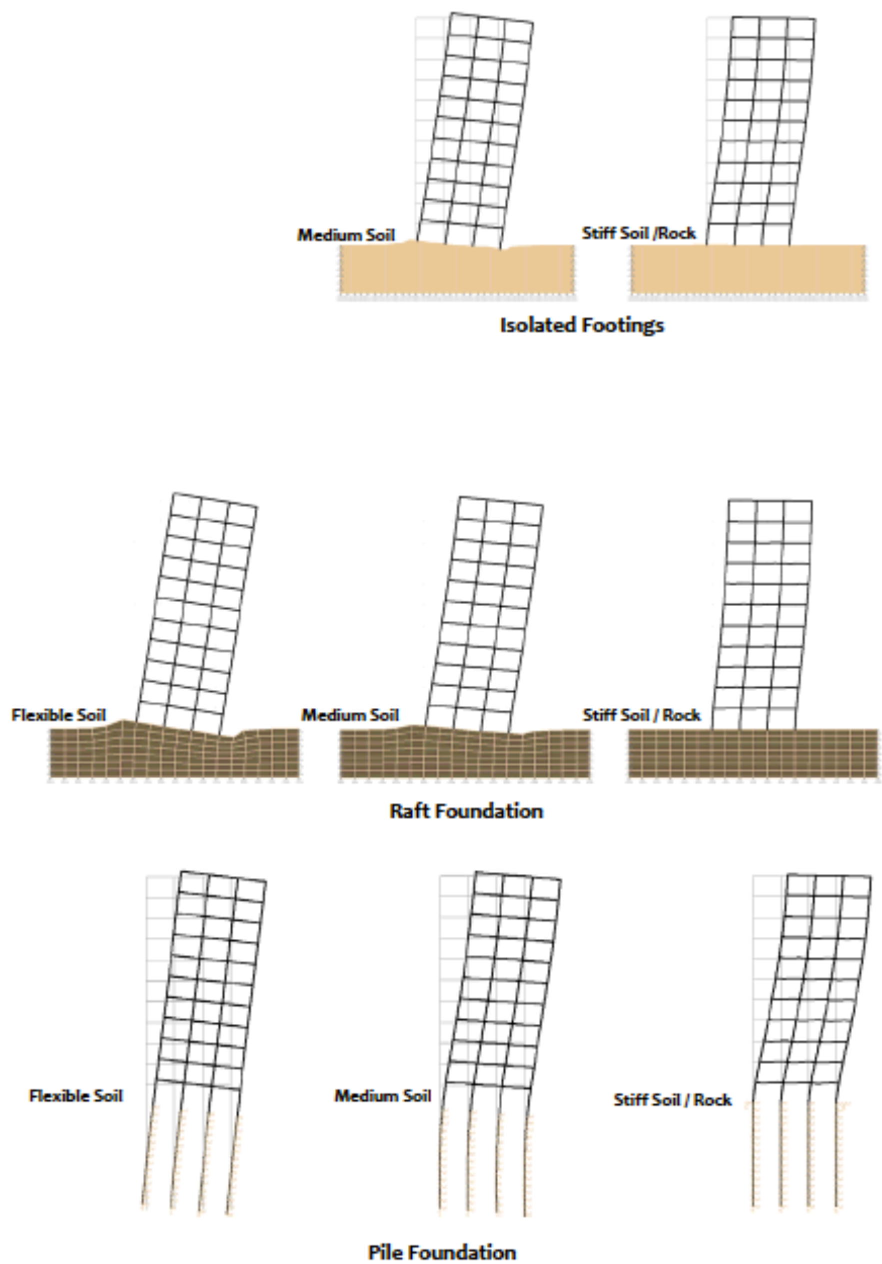

Figure 16: Building Reactions on Foundations[71]

[70] Ibid., 169.

In conclusion, it has been analyzed that:

> "1. Buildings with isolated footings perform poorly when resting on flexible soil systems, especially in high seismic zones, and hence, should be avoided. Preferably, such buildings should be rested on raft foundations.
>
> 2. Large stresses are generated in soils at the windward and leeward edges of the building, when buildings are subjected to large lateral forces, especially when the soil is softer".[72]

What are the design principles

The following design principles can be drawn from the research on building behavior during seismic activity:

1. Regular, convex geometries in plan
2. No projections, short if necessary
3. Small plan aspect ratio, less than or equal to 4
4. Less than 50% cut outs in diaphragm
5. Small slenderness ratio
6. X- or chevron bracing to reduce moment and shear demand
7. Regular structural grid
8. Not set back or step back in massing
9. Evenly distributed masses in plan and elevation
10. Sufficient space between building adjacency, min 1 cm per story

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[71] Ibid., 169.

[72] Ibid., 167.

11. Hard soil types on site

12. Use raft foundations or base isolation

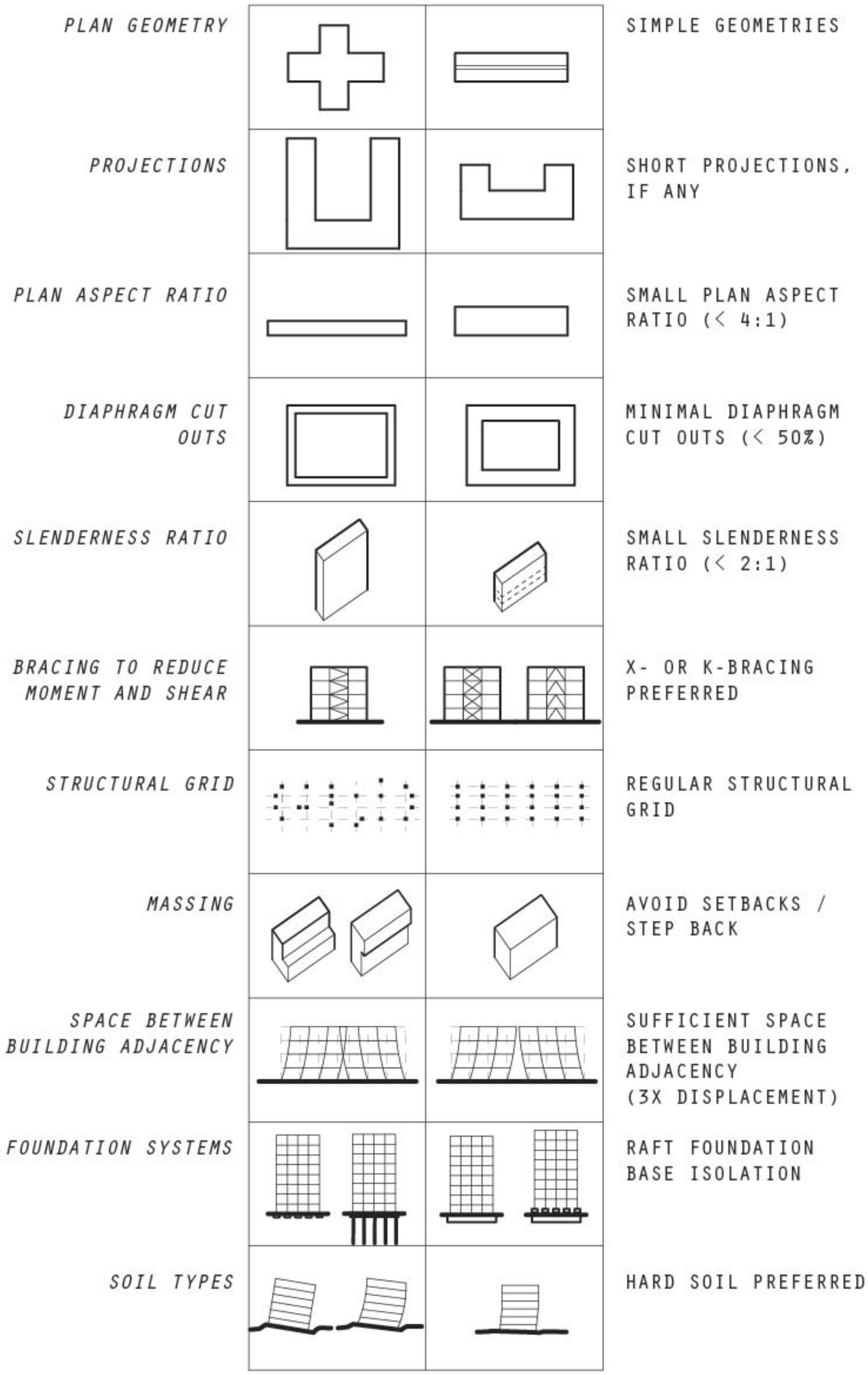

Figure 17: Diagram of Earthquake Design Principles

Chapter 5: New York City as Case Study

How likely is Seismic Activity

Although seismic activity is often associated with the West Coast of the United States, there have been many significant earthquakes in the Northeast, particularly New York State.

Date	Magnitude	Epicenter
1737	5.2	New York City
1884	5.2	New York City
1929	5.2	Attica, NY
1944	5.8	Cornwall-Massena, NY
1983	5.1	Goodnow, NY
2002	5.1	Ausable Forks, NY

Figure 18: Historic Earthquakes[73]

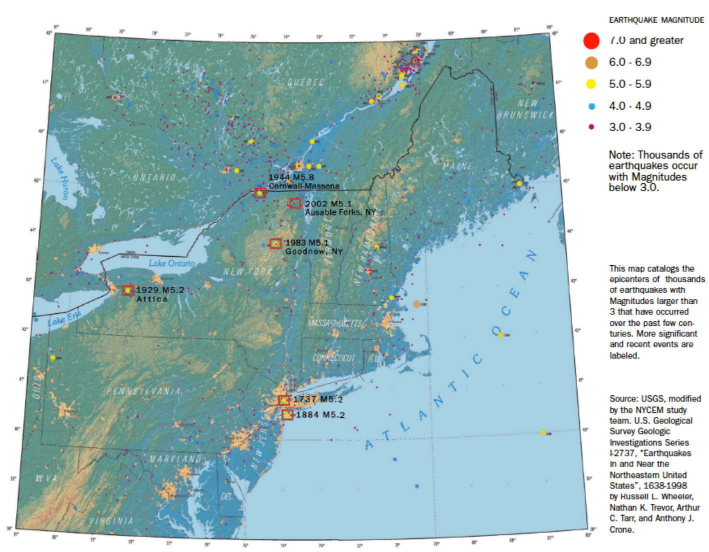

Figure 19: Historic Earthquakes[74]

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[73] "Earthquake Loss Estimation Study for The New York City Area (NYCEM 1st - Year Technical Report)," 12.

While seismic activity can be defined as “moderately” likely in New York City, the following data shows it is a growing concern:

1. “In past centuries, earthquakes with Magnitude 5.0 have occurred about every 100 years in the New York City area. Modern New York City is ill prepared even for such moderate events
2. Larger earthquakes with magnitudes up to 6.8, the probable upper bound, may occur less frequently”.[75]

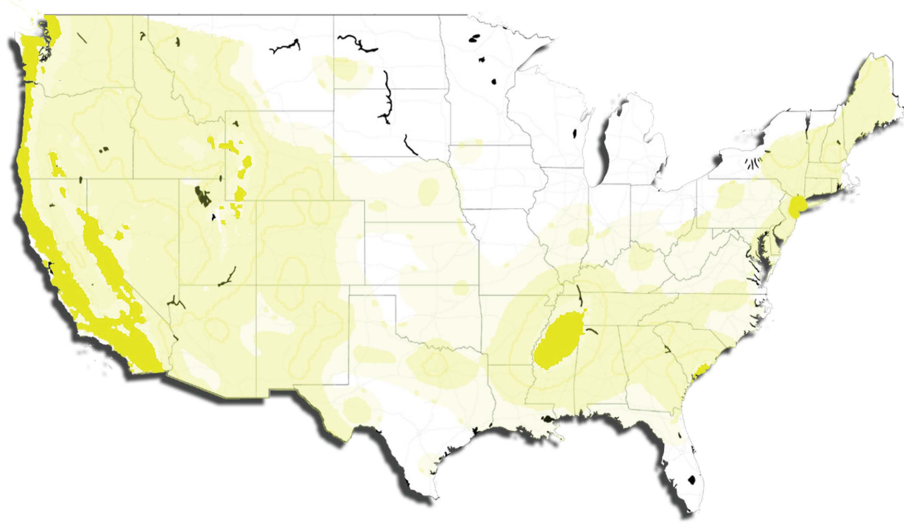

Figure 20: Seismic Zones in United States

[74] Ibid., 13.

[75] Ibid., 12.

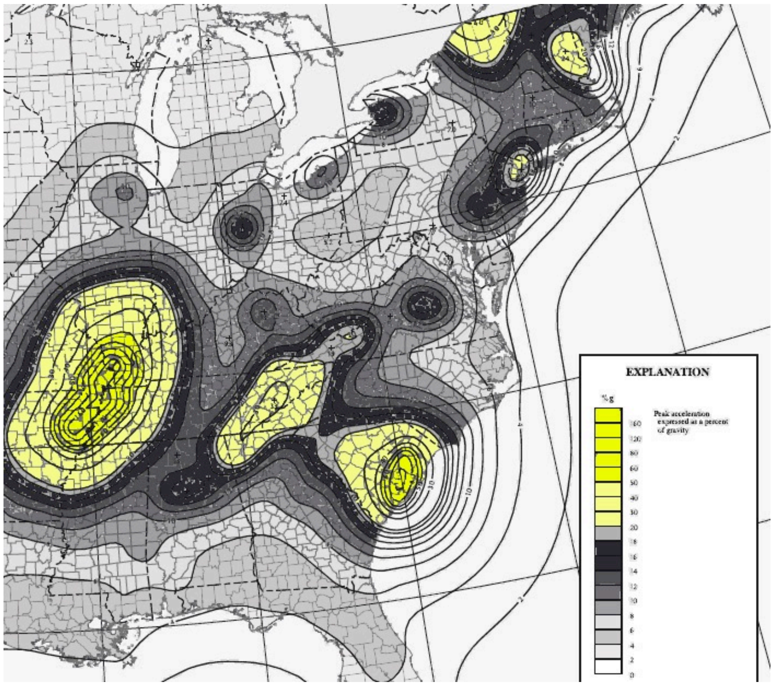

Figure 21: Seismic Zones on East Coast

The New York City metropolitan area is a region that may have low seismic hazard, but has proven to have high seismic risk due to its “tremendous assets, concentration of buildings, and the fragility of its structures, most of which haven’t been seismically designed”.[76]

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[76] Ibid.

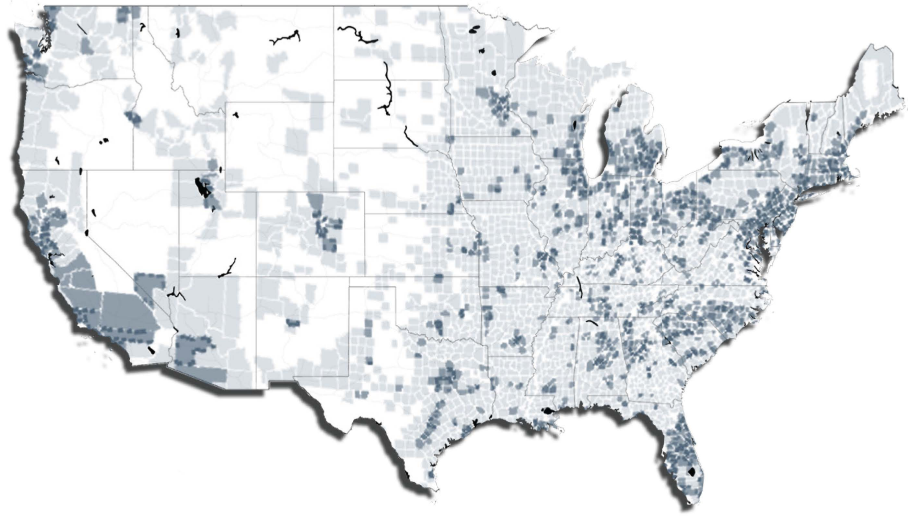

Figure 22: Population Density

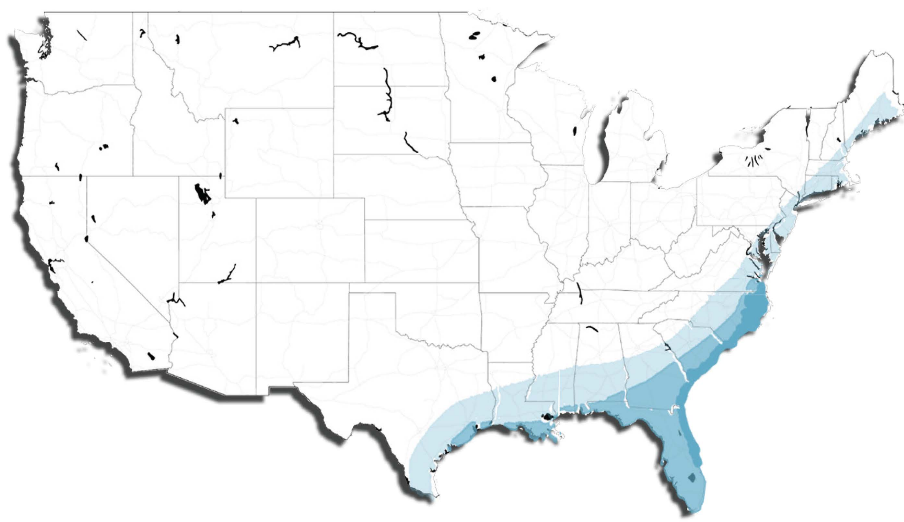

Figure 23: Hurricane Zones

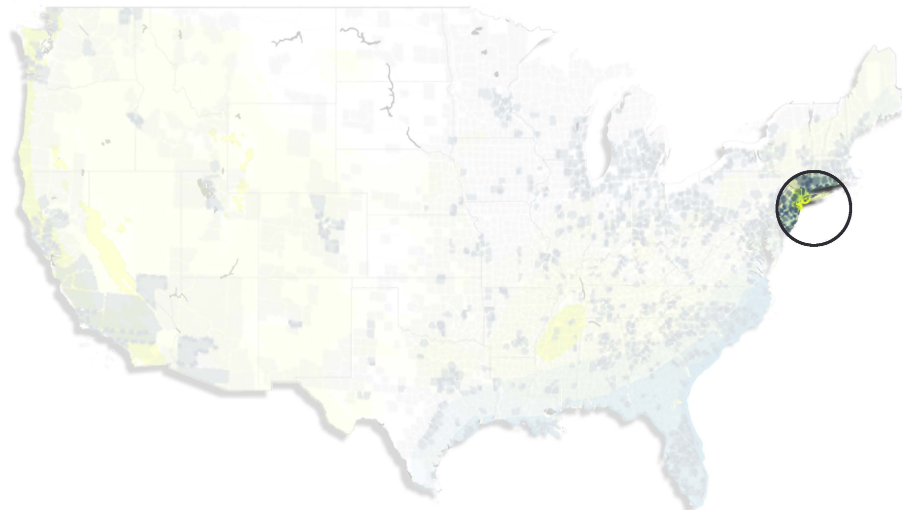

Figure 24: New York City as Area of Study

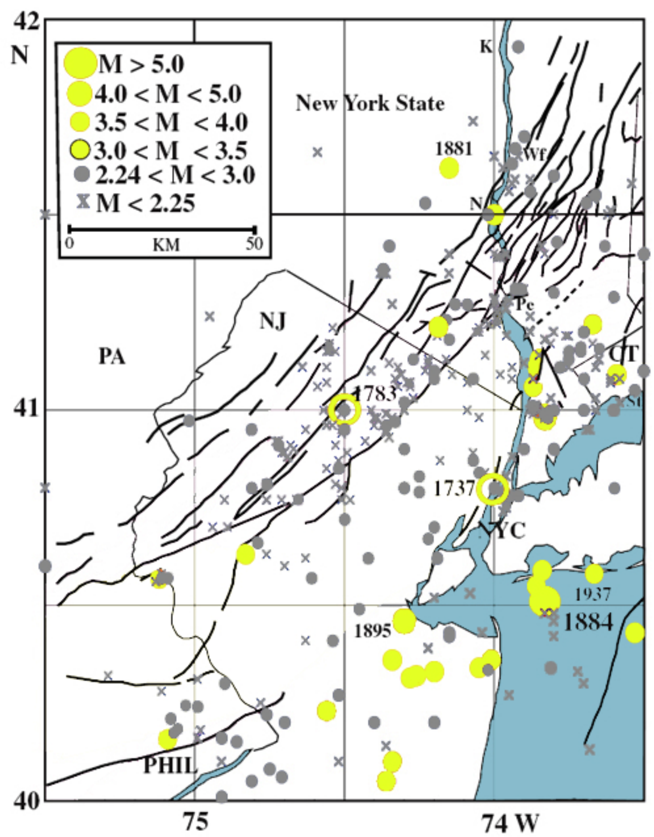

Figure 25: Fault Lines near New York City

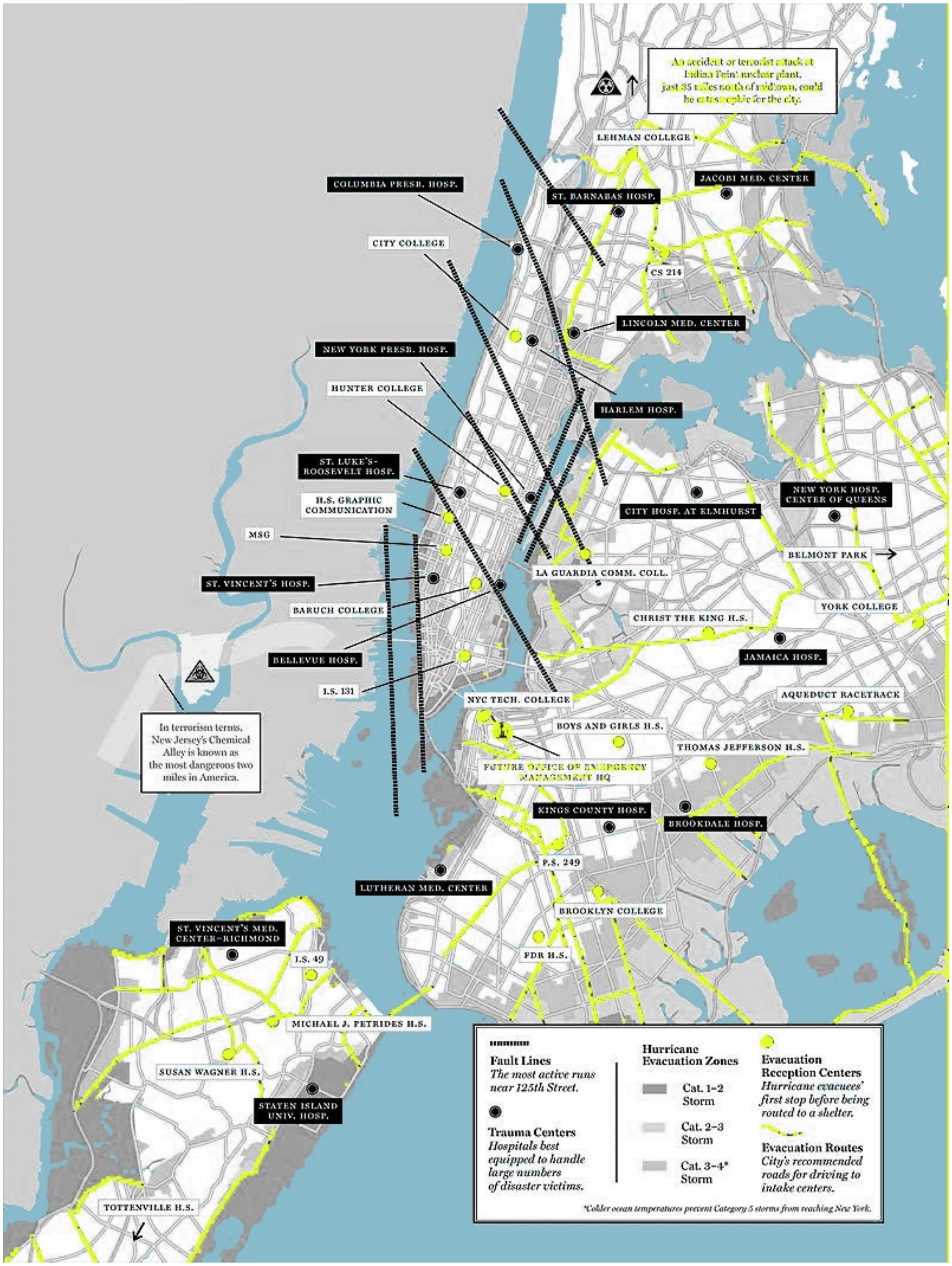

Figure 26: Current Evacuation Plans for New York City

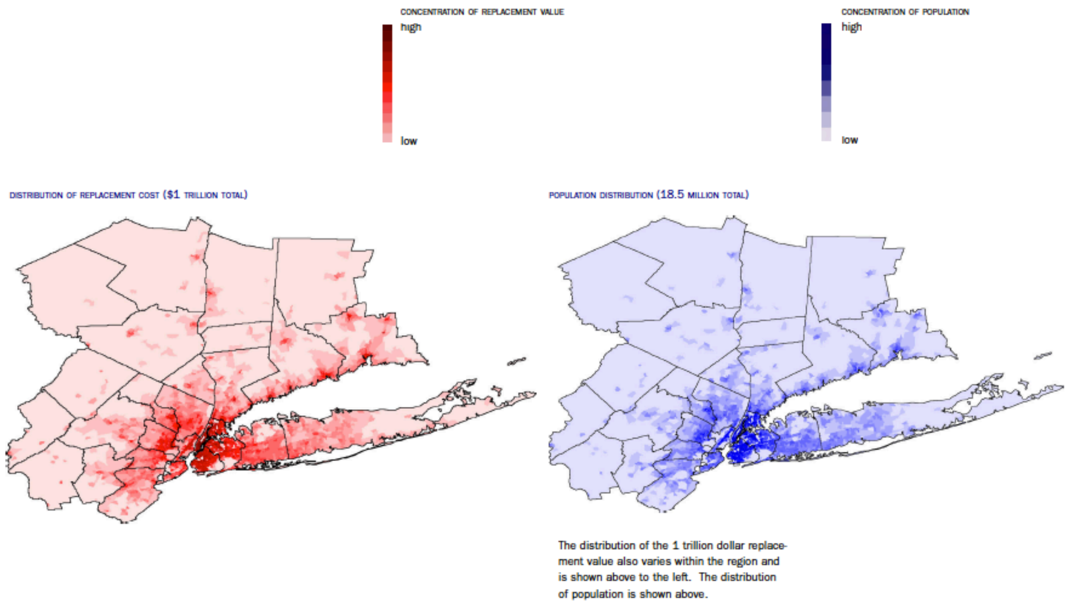

Figure 27: Distribution of Project Losses and Population[77]

Damages Incurred due to Earthquake

While many people associate the East Coast with hurricanes, there are other natural disasters that can be considered "moderately" likely, such as an earthquake in New York City metropolitan area. As assessed by the New York City Area Consortium for Earthquake Loss Mitigation, "earthquakes of magnitude 5.2 have a 20% to 40% probability of occurrence in 50 years".[78] This would be considered particularly catastrophic due to the economic impact of an earthquake in New York City, not to mention the physical damage to infrastructure, housing, and human safety. The estimated tri-state building inventory is valued at $1 trillion in replacement value, excluding contents and lifeline infrastructure systems. So, if an

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[77] Ibid., 16.

[78] Ibid., 6.

earthquake of a large magnitude hit New York City, it can cause $85 billion of damage.[79] New York City has an extremely high concentration of high rise buildings per square foot compared to other American cities".[80] Furthermore, 95% of the building stock is residential.[81] While hurricanes are a greater concern for the region, it is imperative to look at disaster relief as holistic, implementing a multi-hazard approach to mitigation.

If a catastrophic earthquake were to occur, "about 18.5 million people in 7 million households would be at risk".[82] By analyzing the distribution of population and potential replacement value, it is evident that Brooklyn has a particularly dense amount of possible damage. Due to this, there would be a large amount of the population displaced and the indefinable social losses must be considered as well. Even in a moderate magnitude 6 earthquake, almost 200,000 people would be displaced in the region, requiring the use of unconventional facilities used for emergency shelter. Schools in the area can provide temporary public shelters. If a magnitude 5 earthquake occurred, about 2,800 people in the region would need shelter, and schools would suffice to provide them with temporary housing.[83] If,

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[79] Ibid., 7.

[80] Ibid., 177.

[81] Ibid., 12.

[82] "Earthquake Loss Estimation Study for The New York City Area (NYCEM 1st - Year Technical Report)," 12.

[83] Ibid., 33.

however, a more severe earthquake occurred, the existing schools would not be able to accommodate the displaced population.

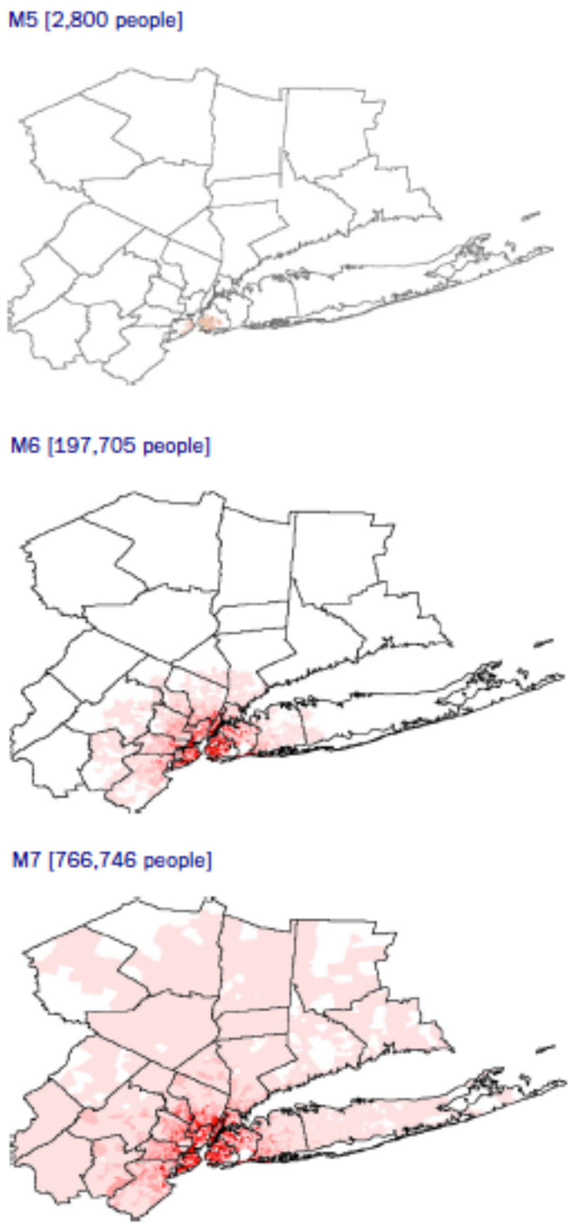

Figure 28: Population Displaced[84]

[84] Ibid., 32.

To summarize, although the New York City metro area has infrequent damaging earthquakes, it has been considered a low hazard/high risk situation, due to its "dense population, vulnerable infrastructure, and substantial economic value".[85] Considering the area's seismic history, dense population, and vulnerability of the built environment, it is evident that a moderate earthquake would have a significant impact on the lives and economy of the Tri-State region.[86] In order to mitigate possible losses before an earthquake, the region must prepare a response before an earthquake to ensure a quick response and relief after an earthquake. The disaster resiliency of the area must be improved and there should be greater promotion of public awareness of the potential problems.[87]

How prepared is the region

Current Preparedness

Due to the lack of concern for seismic activity, the first building codes addressing seismic activity for New York City was passed only in 1995.[88] Therefore, there is a higher potential for building damage in areas developed before that code so that mitigation, emergency response and recovery approaches can be focused on particularly vulnerable neighborhoods. In general, there are a number of socio-economic constraints which delay the implementation of seismic codes: "lack of

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[85] Ibid., 8.

[86] Ibid.

[87] Ibid., 11.

[88] Ibid., 14.

concern about seismic safety due to infrequent occurrence of earthquakes, lack of motivation, lack of financial resources to meet earthquake resistance requirements, and lack of skill in seismic design and construction techniques”.[89]

Mitigate Damage in the Future

If a disaster were to occur in New York City, the disaster relief effort could “serve as a template and for national visionary planning on an integrated and massive scale” for the rest of the country to use as an example.[90] In order to increase preparedness for future disasters, some specific concepts that can be applied to New York City and by extension, the nation, including:

1. “Reduce flooding impact by moving boilers and electrical panels out of basements
2. “waterproof” hospitals, nursing homes, and other critical infrastructure by sheathing the floodable elevations
3. Plan big, but build incrementally
4. Incorporate resiliency concepts into implementation of disaster relief plans
5. Take advantage of wind power
6. Green roofs to absorbs water and blue roofs to hold the water until sewer systems can handle it or for grey water uses

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[89] “03-SP02.indd - Earthquake-Risks-New-York.pdf,” accessed November 26, 2013, http://mceer.buffalo.edu/infoservice/disasters/earthquake-risks-new-york.pdf.

[90] “‘Resilient Infrastructure’ - brkprsericksonapr10.pdf,” 18, accessed November 26, 2013, http://view.fdu.edu/files/brkprsericksonapr10.pdf.

7. Antimicrobial coatings to reduce infections in hospitals, locker rooms, and other confined areas,
8. Permeable pavement to allow surface water to seep back into earth after being filtered". [91]

It is important that this intervention raises public awareness about the impending risks and hazards on natural disasters.

[91] Ibid., 20.

Chapter 6: Site Selection

What elements are important

Once a disaster occurs, and residents are displaced from their homes due to structural damage, it is essential to provide them with a safe shelter as quickly as possible so they can attempt to return to normalcy. When beginning to locate a site for a disaster relief housing site, it was imperative to outline the characteristics that would define the optimal location.

Alternative Access

In the aftermath of an earthquake, there is major structural damage to buildings and infrastructure, including street systems, utilities, and transportation networks. Street damage is particularly detrimental because it makes transporting goods and shelter to the site difficult, or even impossible. It can take weeks or even months to clean up the debris, and can take even longer to restore the damaged infrastructure. In order to transport the materials to develop an emergency structure, the site must be accessible by alternative transportation. One system of transportation that would not be as severely affected by seismic activity is watercraft. Locating the site near a dock and marina would be ideal for bringing in materials.

Figure 29: Water Transportation Access

Figure 30: Public Transportation (Subway and Ferry)

Flood Resistant

While the structures should be able to withstand a future earthquake, they should also be safe if a catastrophic hurricane hits the region. In order to predict this, it is important to analyze the predicted storm surge areas from a Category 1 to a Category 4 hurricane. This data can be compared to the flooding maps from Hurricane Sandy's destruction of the city in 2012. The site must be located outside of these flooding boundaries, which can best predict where future flooding may occur.

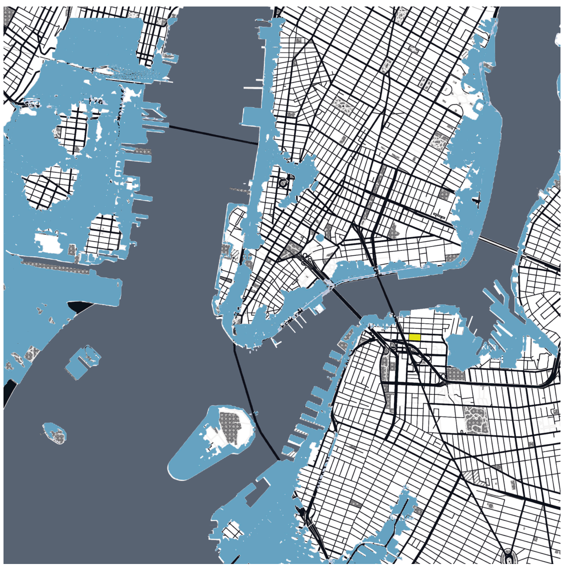

Figure 31: Areas Flooded during Hurricane Sandy[92]

[92] "Flooding and Flood Zones | WNYC," accessed November 26, 2013, http://project.wnyc.org/flooding-sandy-new/#15.00/40.7361/-74.0174.

Figure 32: Areas Flooded during Hurricane Sandy

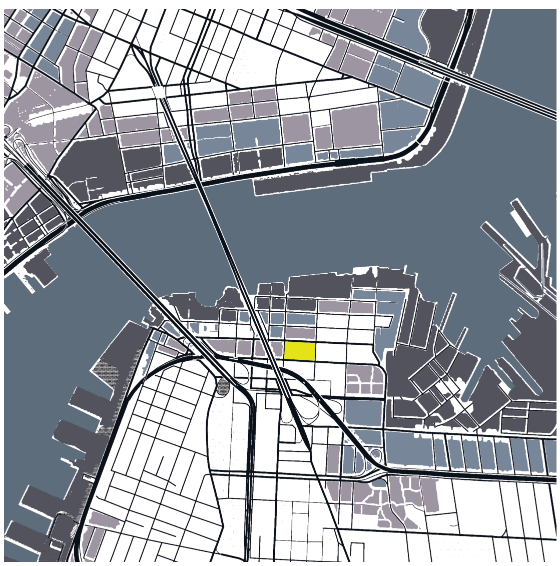

Figure 33: Predicted Flooding during Category 1,2,3 and 4 Hurricanes[93]

Open Land – "Disaster Resistant"

In order for a disaster relief site to be immediately used for emergency shelter, it must be relatively unaffected by the natural disaster. In this particular case of

[93] Ibid.

shelters after an earthquake, it is essential that the site be as free of debris as possible. Thus, the site will need minimal attention before the materials to build the shelter arrive. Also, a site that does not currently have a building located on it will make the construction of the emergency shelters that much quicker since it will not require any type of demolition or clearing of the site.

Proximity to Community

Another consequence of a natural disaster is the social disruption of the community. The residents are out of work, their homes may be destroyed or uninhabitable, and they must be relocated to large group emergency shelters, sometimes very far from their neighborhood. In an attempt to minimize this problem, a site that is located in close proximity to the existing neighborhood is ideal, helping to create a sense of normalcy as soon as possible. The same strategy may also provide the residents with the option of permanently relocating to the shelter. Once the relief and recovery phases have passed, the residents will still be close to their schools, jobs, and neighbors.

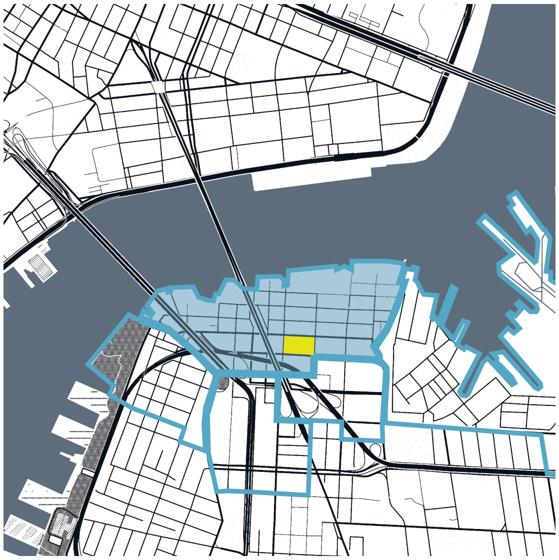

Figure 34: Proximity to Community

Figure 35: Existing and Proposed Pedestrian Routes

Access to Existing Infrastructure

Lastly, access to existing infrastructure is ideal because it will decrease the amount of time required to prepare the site for the emergency structures. If these units transition to become permanent housing units, it is essential that the proper infrastructure can be accessed to provide the necessary utilities. Disaster infrastructure that can "evolve from meeting basic survival needs to temporary structures and systems that are livable, pleasing, and humane" would be ideal to become permanent residences.[94] Therefore, it is preferred that the site is surrounded by development with utilities that the recovery community could then plug into as seamlessly as possible.

Soil Quality

In order for this development to be an example of good building practices to prepare for the various types of natural disaster that may occur, it is important this site is on sufficient soil to be structurally sound in order to resist a future earthquake. Most of New York City's waterfront is made up of landfill material, which during seismic activity, is prone to liquefaction, which can severely damage any structures that are located on it. Soil liquefaction occurs when soil substantially loses its strength and stiffness in response to an applied stress, typically a seismic event. Preferable soils would have an allowable bearing capacity of more than 10 t/m2.[95] Therefore, it is important to locate a site that is on hard, solid soil to allow for better building behavior during an earthquake.

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[94] "'Resilient Infrastructure' - brkprsericksonapr10.pdf," 10.

[95] "E_Chapter2.pdf," accessed November 26, 2013, http://www.nicee.org/iaee/E_Chapter2.pdf.

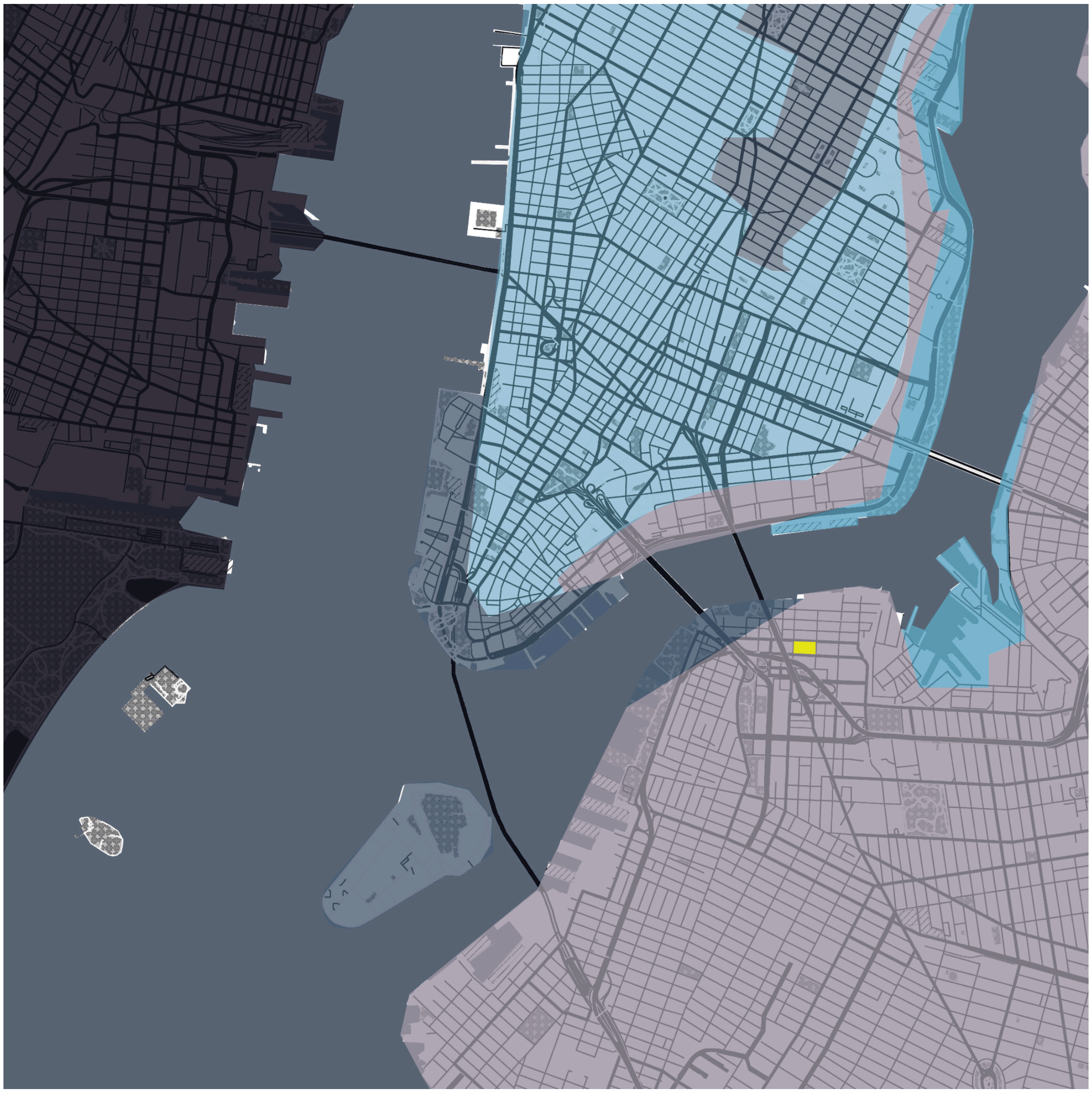

Figure 36: Soil Types[96]

[96] "Earthquake Loss Estimation Study for The New York City Area (NYCEM 1st - Year Technical Report)," 20.

Site Analysis

Site Location

By overlaying the essential factors for a suitable site, the block bounded by York Street, Jay Street, Front Street and Bridge Street is one of the possible sites available to test this intervention. It is located only two blocks away from the Brooklyn Navy Yard, which will provide the alternative transportation needed to deliver the shelters. As per the Vision 2020 plan for New York City, the Brooklyn Navy Yard will "explore opportunities for controlled public access, support preservation of historic structures, and open an exhibition and visitors center".[97] Many other sites in the area have also been designated as areas for improvement including the ConEdison site at Division Ave, which will "explore options for redevelopment for industrial and/or commercial uses with opportunities for public access if appropriate".[98]

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[97] "Vision 2020 - vision2020_nyc_cwp.pdf," 144, accessed November 26, 2013, http://www.nyc.gov/html/dcp/pdf/cwp/vision2020_nyc_cwp.pdf.

[98] Ibid.

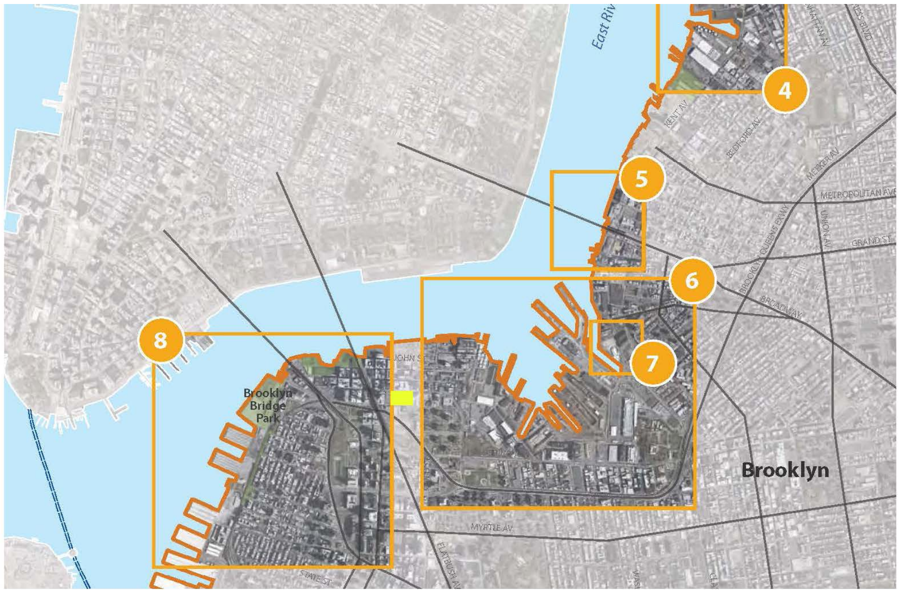

Figure 37: Future Areas of Development

Figure 38: Available Site

In addition, the Brooklyn Bridge Park area will incorporate “active, passive and in water recreational uses, residential and hotel uses, improvements to the pedestrian bridge, improved connections with neighboring street network to provide a safe and cohesive access to the park, and develop a greenway linking the Columbia St.

Greenway to Dumbo".[99] With these major development projects in the works for the next decade, this chosen block is at a pivotal location to be very attractive to residents wishing to live in Brooklyn.

Figure 39: Site Amenities

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[99] Ibid., 144.

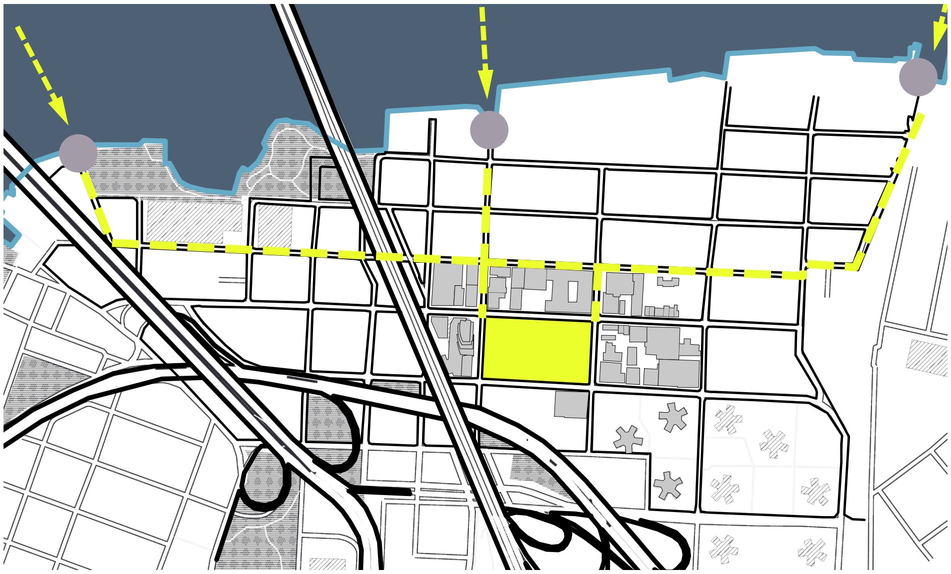

Figure 40: Water Transportation Access to Site

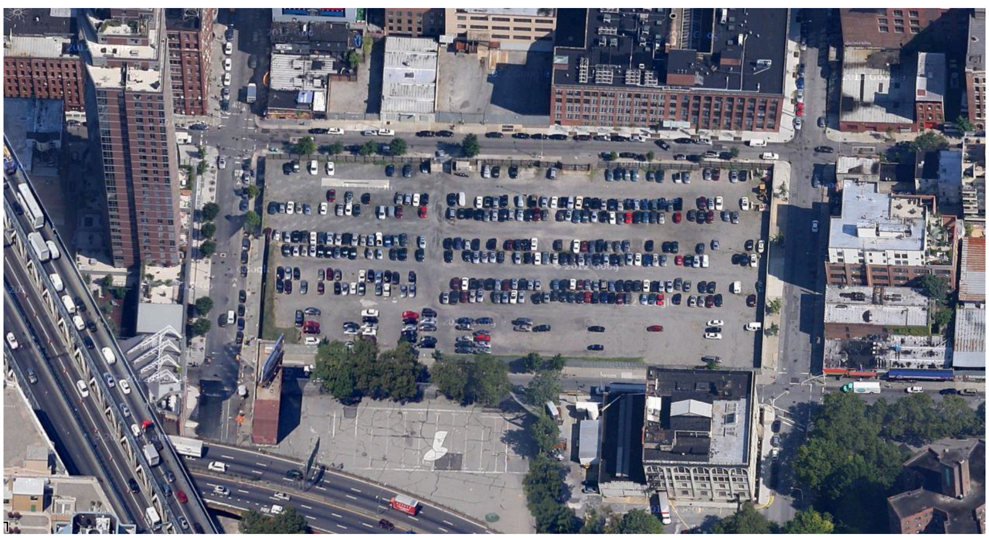

Figure 41: Available Site

Site Research

Through research of the neighborhood, an analysis can be conducted to understand the context. Census Tract Regions 21, 1, 13 and 23, which includes DUMBO, have approximately 14,000 residents collectively. If the designate residential buildings that were built before 1920, thus assuming they are constructed of unreinforced masonry, it is understood that those residents will be displaced due to building damage or complete destruction. If 10% of the entire community is displaced, the disaster recovery community should be designed to hold a density of 1,400 people.

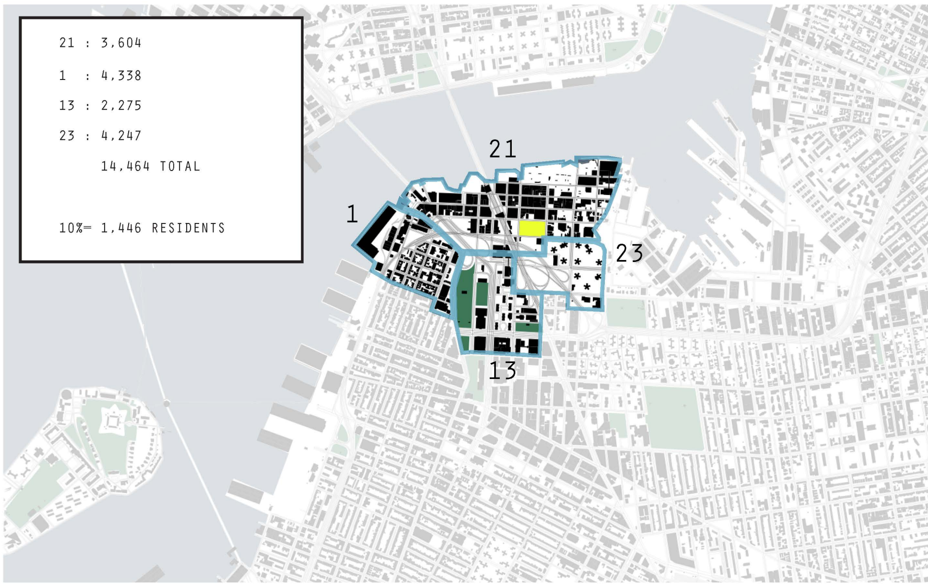

Figure 42: Census Tract Boundaries

Figure 43: Building Inventory in Neighborhood[100]

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[100] "PLUTO Data Tour," accessed November 26, 2013, http://andrewxhill.github.io/cartodb-examples/scroll-story/pluto/index.html#5.

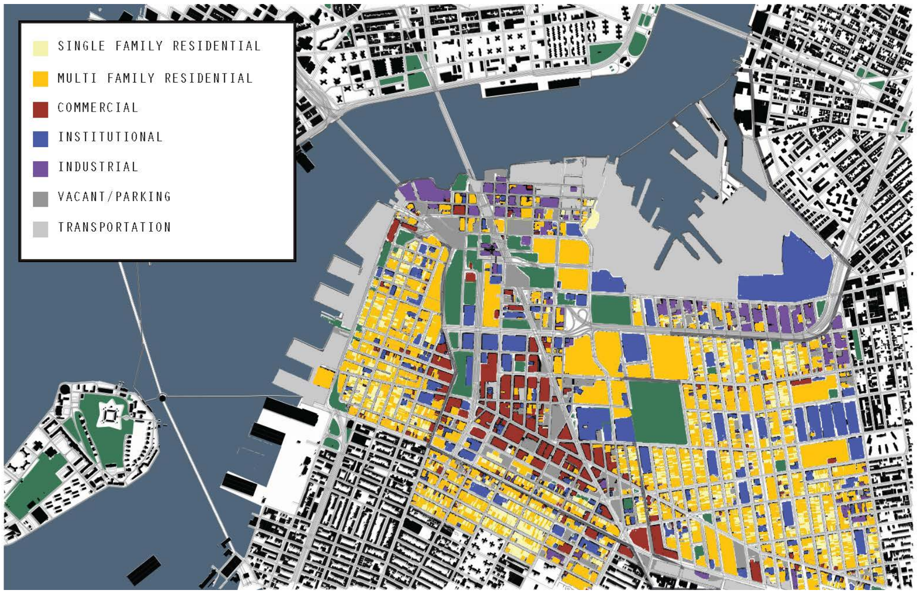

Figure 44: Land Uses (Residential)

Figure 45: Residential Buildings Built before 1920 (in danger)

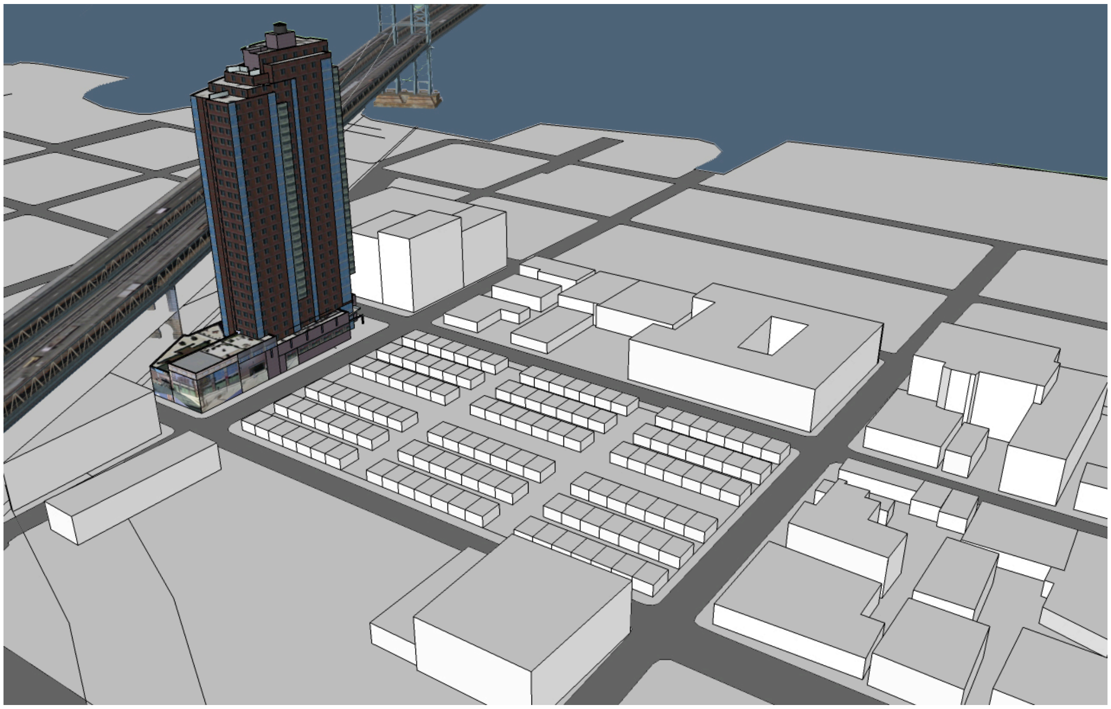

Figure 46: Density Massing 1 (500 residents)

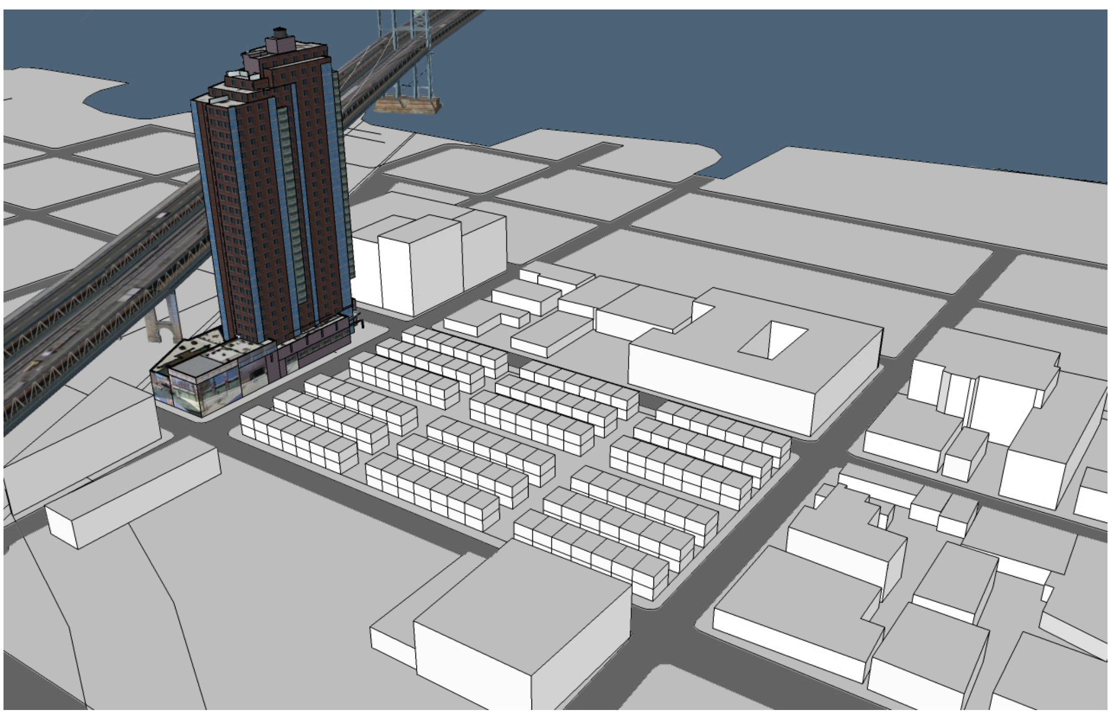

Figure 47: Density Massing 2 (1000 residents)

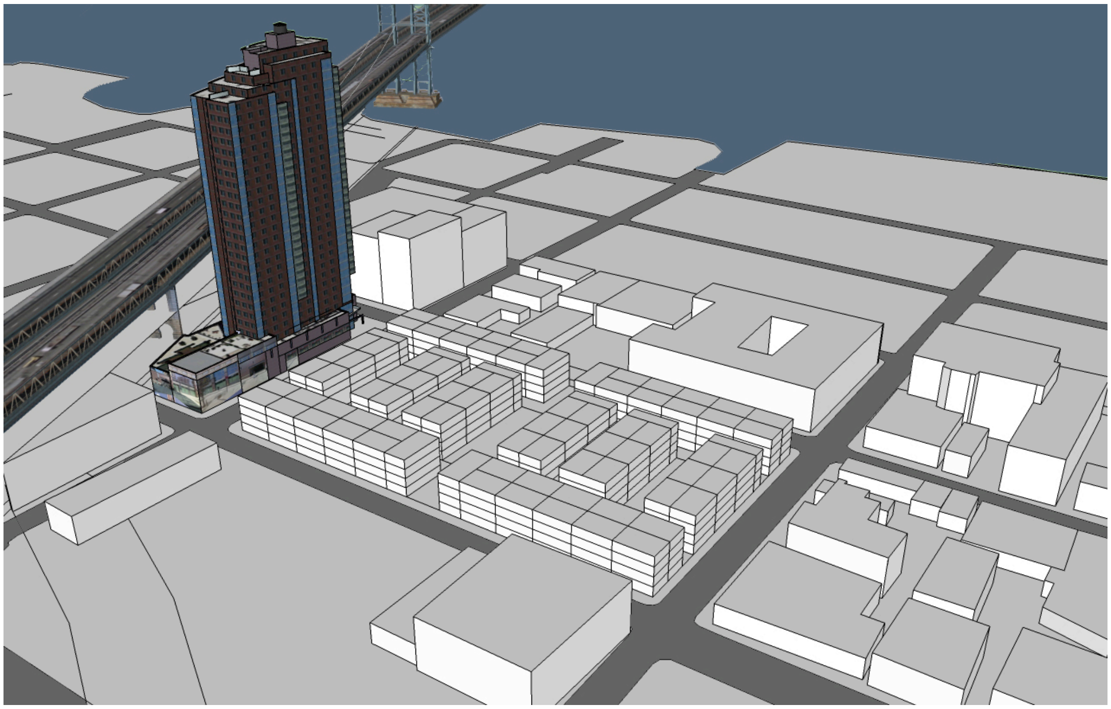

Figure 48: Density Massing 3 (1,200 residents)

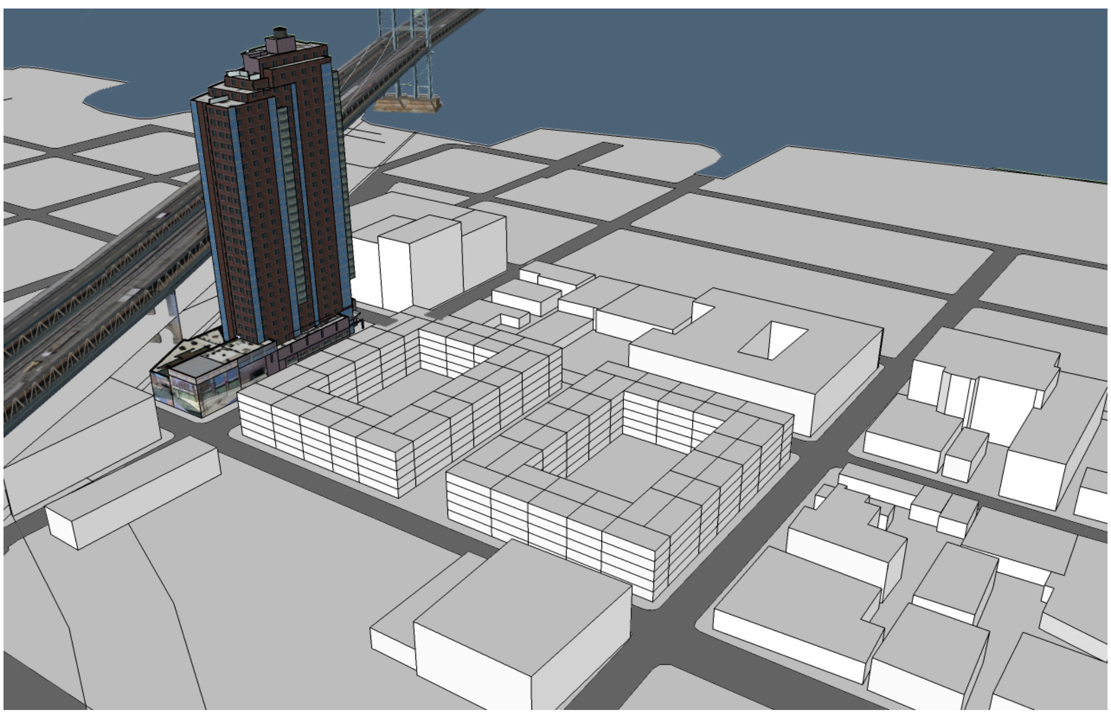

Figure 49: Density Massing 4 (1,400 residents)

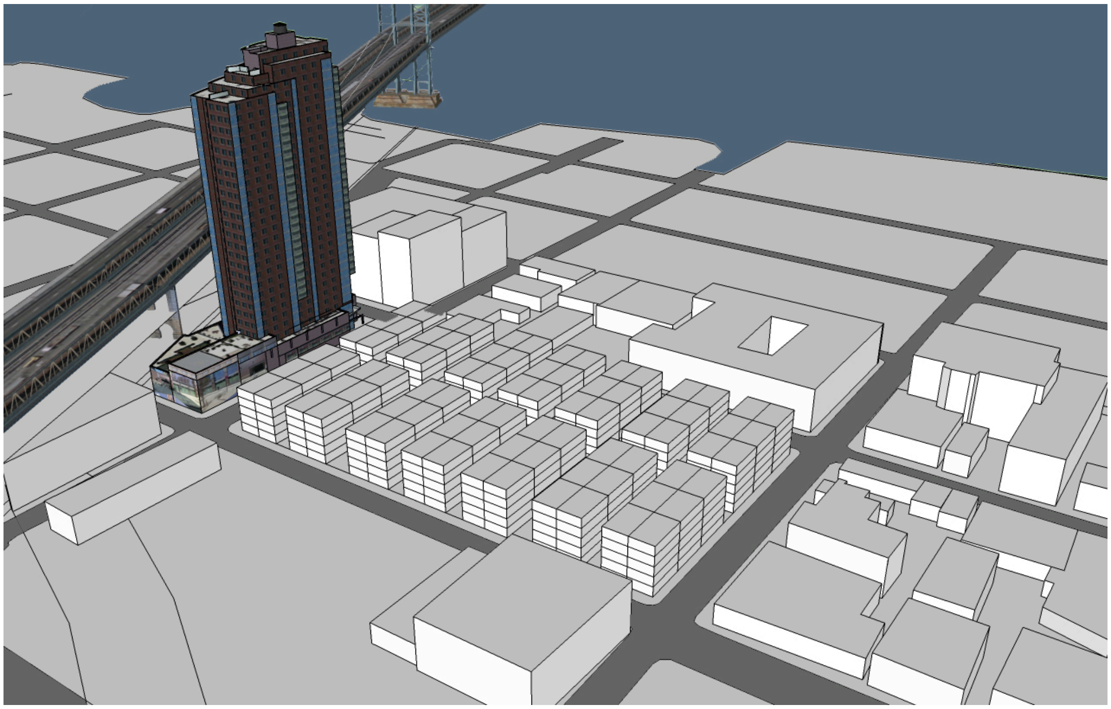

Figure 50: Density Massing 5 (1,680 residents)

Chapter 7: Design Objectives

What are the goals of intervention

This design intervention will focus on addressing these goals: how to design a housing response before the disaster occurs to promote a rapid recovery and act as a billboard of research to raise public awareness of the risk of natural disasters. In order to identify a solution, there must be a resolution of the existing dichotomies.

What are main design objectives

In order to design a successful intervention, the most important principles to draw upon are rapid assembly, rapid fabrication, the use of unskilled labor, connections to existing infrastructure, resistance to seismic activity, flexibility, accommodation of community density, and fit into character of community while acting as a beacon of design innovation and public awareness.

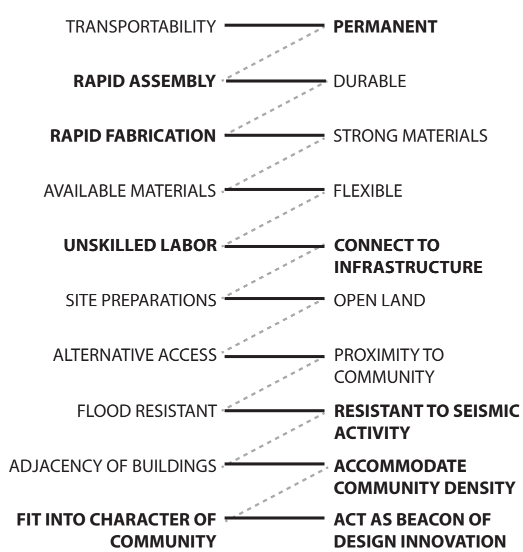

Figure 51: List of Present Dichotomies

While this design should act as a prototypical intervention, the amount of shelters needed will not be known until the disaster occurs. Therefore, it is not ideal to produce and then store hundreds of modules to then be assembled on site. Consequently, a system should be developed to rapidly fabricate the kit of parts required to assemble the structure immediately following the disaster. In order to also accommodate available and affordable materials, a computer numerical control machine, also known as CNC milling, can be used as an efficient and economically feasible system. Once a disaster occurs, CNC mills around the region can be utilized to cut the kit of parts out of a material, such as plywood. When the pieces are milled, they can be flat packed and shipped to the disaster relief site, ready for assembly. The ease of transportation is also ideal for a location that may be damaged by seismic activity because shipping containers can carry many "kit of parts" simultaneously. This system has been used for similar purposes before in smaller scale structures and could be scaled up to accommodate a larger displaced density.[101]

An open source architecture initiative has been developed to share architecture designs across the world by using Google SketchUp and a plug-in that exports the design into CNC milling format to produce the pieces.[102] In the case of WikiHouse, two people can assemble the design in one day. The ideas and programs are shared and available for free so that the designs can be altered for the area's specific purposes. This democratization of architecture can be an ideal model for disaster relief structures, where ideas can be shared and constructed in many different regions for different purposes.

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[101] "WikiHouse," accessed November 26, 2013, http://www.wikihouse.cc/.

[102] Ibid.

These structures can then transition to become permanent housing options, which would require more stable elements, including connections to infrastructure. At first, electricity is the most important utility to restore, as well as waste management in order to control health and safety hazards. Once these utilities are reinstated, the rest of the infrastructure can be developed in the following months. A group of students from Princeton University have won the P3 Student Competition to design a rapidly deployable renewable energy system for areas affected by disasters that are left without infrastructure".[103] This prototype for a solar and wind power station that fits within a shipping container is one of the many innovative infrastructure solutions that are available post disaster. The system is made up of a 40-foot tall "10 kW wind turbine, solar panels, batteries for energy storage, and the circuitry and mechanical systems necessary to erect and harvest energy from the hybrid system all packed into a standard shipping container for efficient deployment".[104] While this form of energy may not be sufficient for permanent lifestyles, it can provide emergency energy to maintain safe and healthy environments until the structure can be connected to the municipal infrastructure.

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[103] "Power in a Box: Princeton's Disaster Relief Solar and Wind Generator Fits in a Shipping Container | Inhabitat - Sustainable Design Innovation, Eco Architecture, Green Building," accessed November 26, 2013, http://inhabitat.com/power-in-a-box-princetons-disaster-relief-solar-and-wind-generator-fits-in-a-shipping-container/.

[104] Ibid.

If these units are to become permanent residential units, they must be flexible enough to accommodate different residents' needs. Since the structure will be made up of modular segments, permanent units can be made up of one, two or three emergency units to accommodate a better quality of life. However, providing the necessary design decisions initially is essential to its future success. By using a modular system on the interior as well, it can provide flexibility and personalization for the permanent residents.

In the example of MIMA house, the interior snap track system is provided with a set of interior parts that can be purchased separately.[105] This system makes the frame of the house usable for any resident, whether they would like one bedroom and a living room, or one large open space. The scale of the walls also allows the user to adjust and change the interior in just a few minutes.[106]

Site analysis of the neighborhood will be required to understand the building inventory and population density. Once this data can be determined, it will be evident how many people will be displaced from their damaged homes and will require transitional housing options. Using this data, the design of the development should be able to accommodate the population that is displaced. In general, this neighborhood is typically made up of mid rise buildings, anywhere from four to six stories on average, with some newer, taller buildings as well. As this development will be permanent, it

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[105] Ibid.

[106] Ibid.

should be able to seamlessly be integrated to the scale and needs of the community to ensure its acceptance.

However, while the intervention should fit into the neighborhood, it also should have certain design features that define it as a beacon of innovation and act as an example to raise public awareness of seismic hazards and mitigation. If it is used as a teaching tool, other existing and proposed structures can integrate similar design principles to ensure the future success and safety of these buildings.

Design Process Options

When designing this process of recovery, the separate options must be divided into alternatives. The first option is to focus on designing a culturally and regionally responsive temporary structure. The main goals will be to design the details of the design to create a transportable prototype for the city. This process would also include identifying available sites in order to place these structures in close proximity to the community. The structures will be designed to last up to two years in order to provide sufficient time to restore the damaged residential buildings. Afterwards, the structures will be removed and possibly reused for another purpose, or dismantled for the materials to be salvaged. However, this is not directly addressing the issue of the thesis, as these structures are not directly contributing to the revitalization of the community.

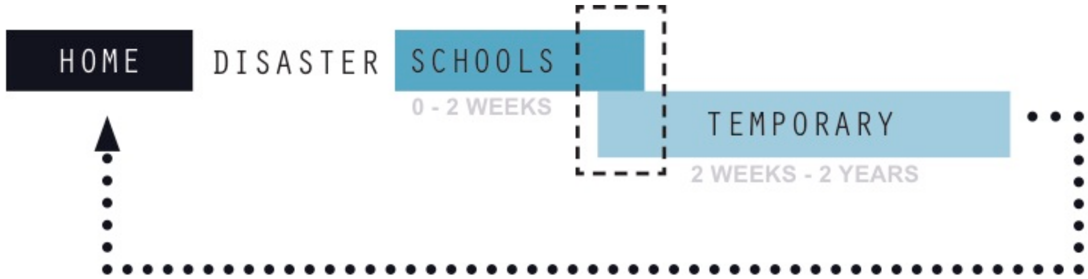

Figure 52: Process 1, Temporary Structure

Figure 53: Process 1, Possible Available Sites

The second option is to develop a phasing plan for the site. If the available site can be divided and developed at different rates, it can provide housing options for all phases of the recovery process. This process would focus on the assembly and disassembly of units in order to prepare for the final permanent phasing of the site. A option would be to reuse the previous phases for another purpose. The question remains of how to reduce the material waste and also to consider the development of the final result.

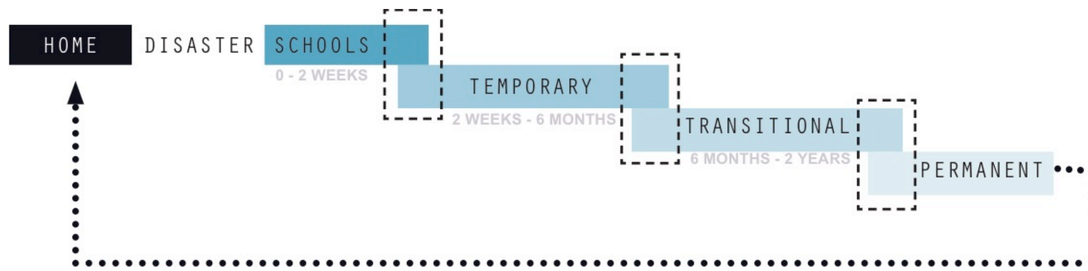

Figure 54: Process 2, Phasing of Site

Figure 55: Process 2, Phasing of Site

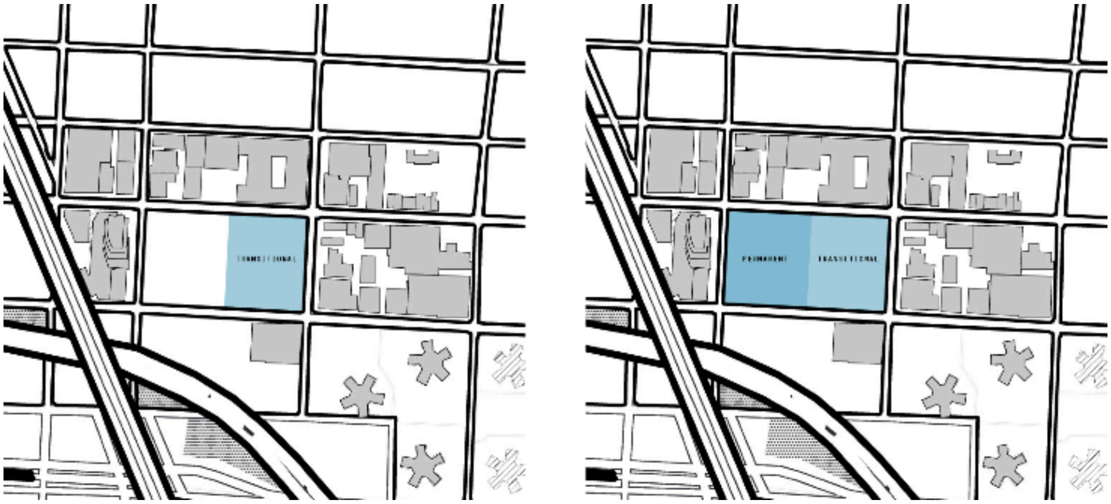

Figure 56: Process 2, Phasing of Site

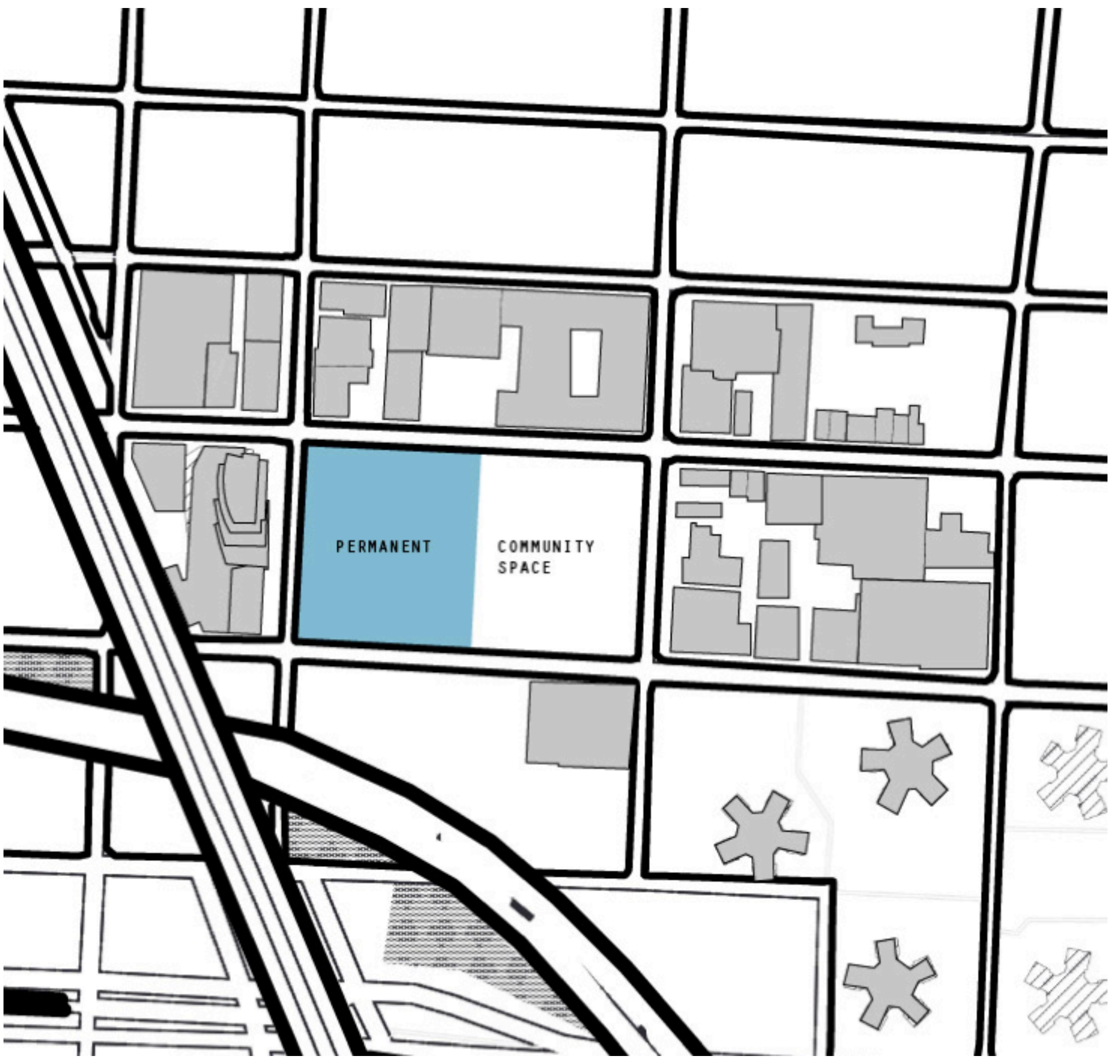

Figure 57: Process2, Final Phase of Site

The third design process option is to find a system to connect to the existing infrastructure once it is restored. The focus will be on the physical changes that need to occur to transition from temporary to permanent, mainly how to provide utilities to the residents permanently. One thing to consider is the timeframe of the restoration of the infrastructure and how to remove the temporary energy systems that are in place. There may be flexible options available to combine units for permanent use or connect multiple units to be used for communal space.

Figure 58: Process 3, Connect to Existing Infrastructure

Figure 59: Process 3, Connect to Existing Infrastructure

The final alternative includes designing a permanently "off the grid" disaster recovery community. If the development is "off the grid", it will generate the amount of energy the community needs in order to thrive. However, this raises questions of feasibility; how much renewable energy be needed to support the 1,400 residents? However, a self-sustaining community would be able to withstand another natural disaster, as well as possibly provided excess energy for the rest of the community.

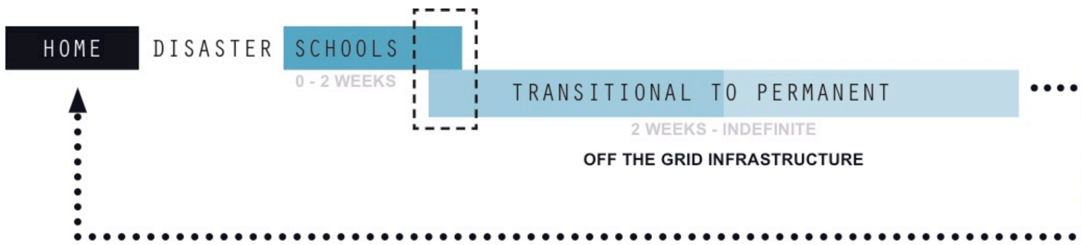

Figure 60: Process 4, Off the Grid

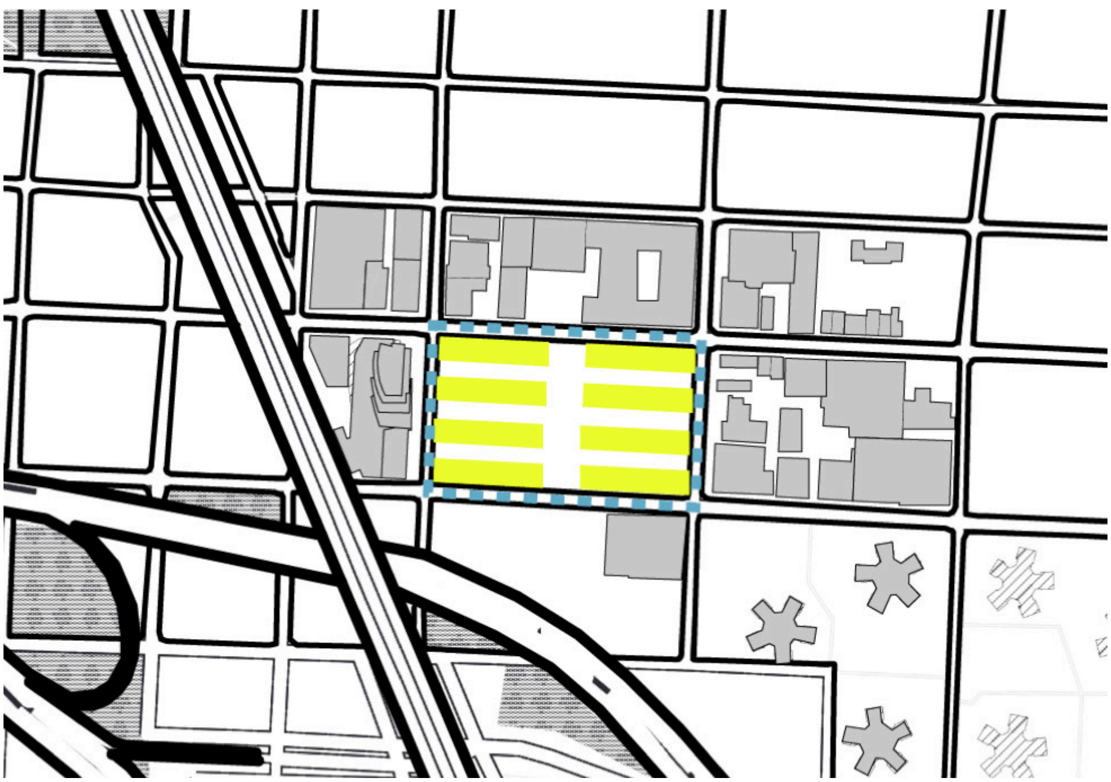

Figure 61: Process 4, Off the Grid

Each of these design process options attempts to resolve the existing contradictions that are present in the thesis statement. In order to combine the main goals, including providing a medium density residential community within a compressed timeframe that can be durable and become a permanent development, the design process must be designed to accomplish these objectives.

Chapter 8: Design Implementation

Design Implementation

In order to accomplish the goal of a building developed incrementally while also addressing the neighborhood's urban density and urban intensity, it was essential to outline a series of phases of the building's life cycle. The implementation of these phases is contingent upon the occurrence of a natural disaster that leads to displacement. The series of phases include the community amenities, followed by the completion of the frame, then the deployment of the emergency units, and finally the relief and recovery phases.

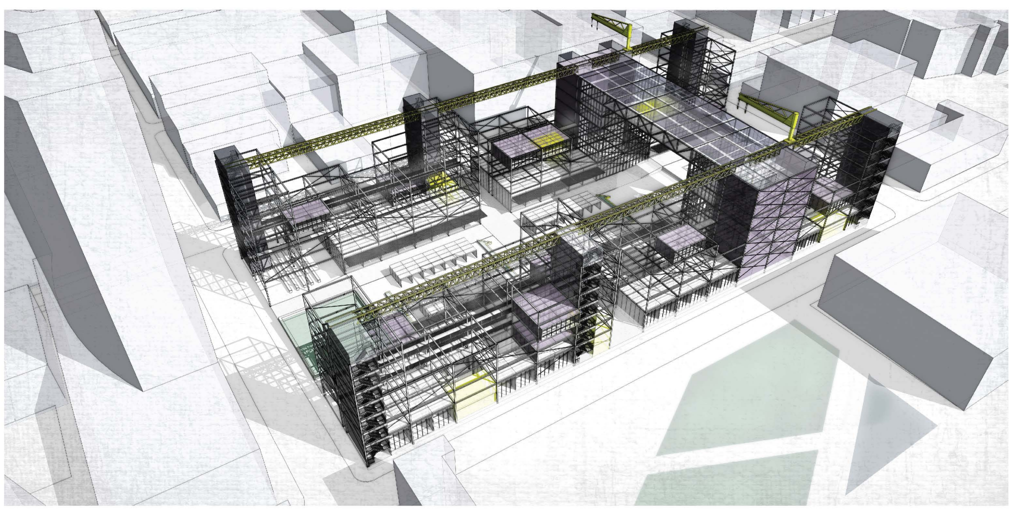

Figure 62: Phase 1, Community

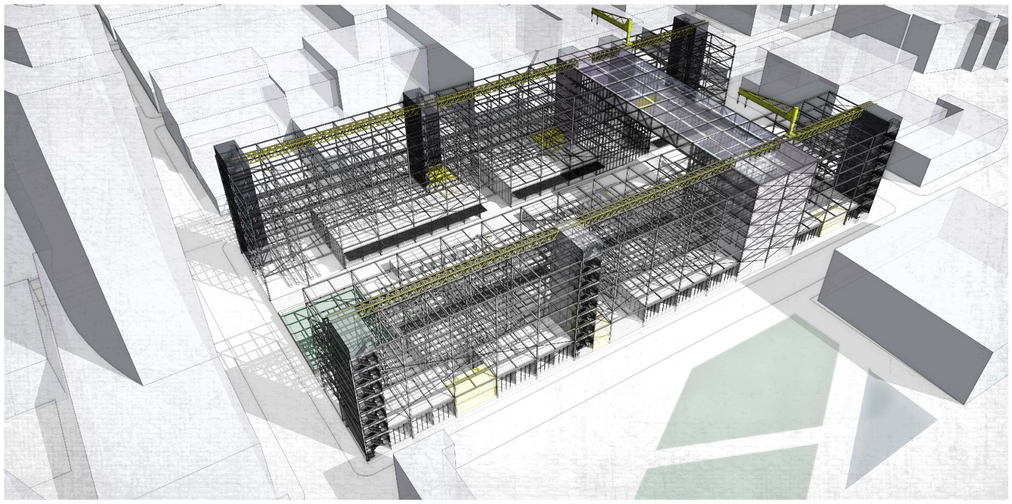

Figure 63: Phase 2, Frame

Figure 64: Phase 3, Emergency

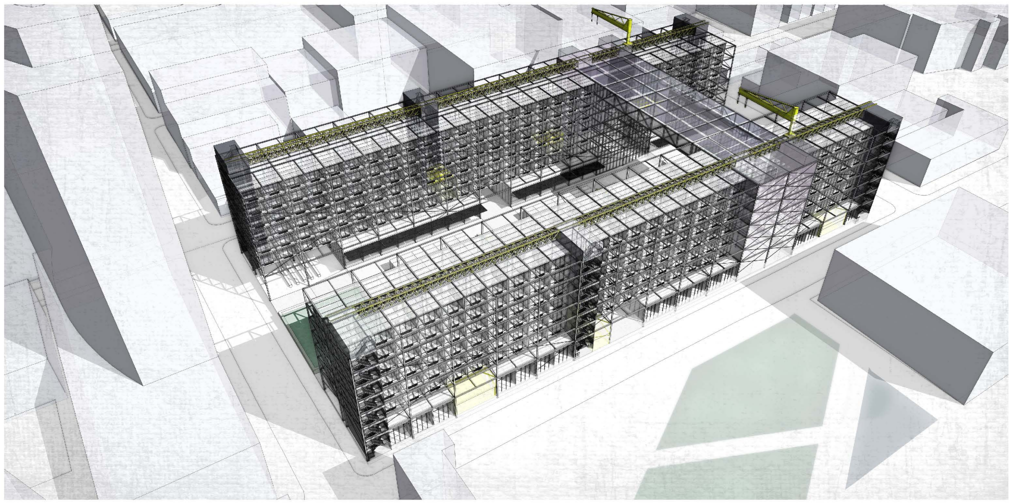

Figure 65: Phase 4, Relief

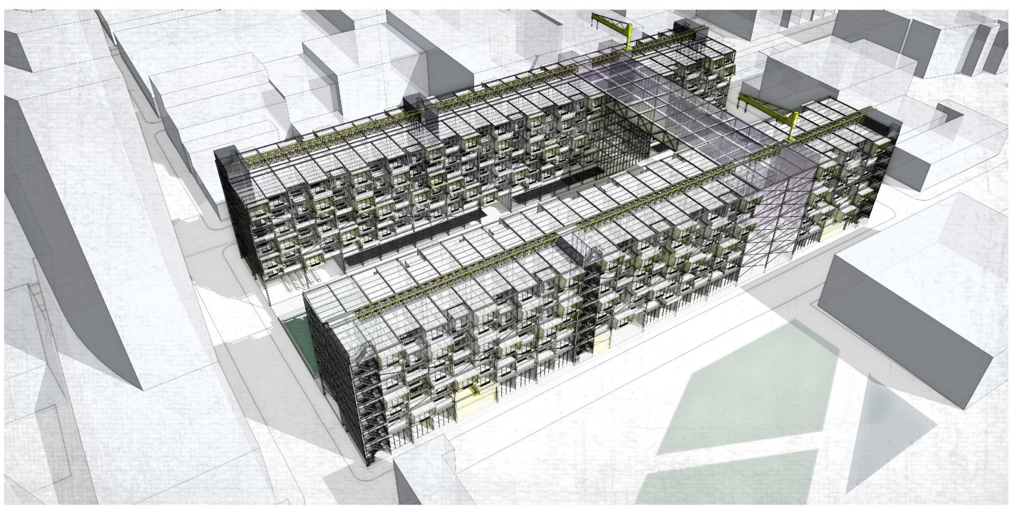

Figure 66: Phase 5, Recovery

During the community phase, which is part of the prepare phase, it is essential to provide a vast array of programmatic elements and activities to be developed within this block. By combining community uses with retail, art space, and market space, the neighborhood will be drawn to this site, making this a new outdoor plaza for the neighborhood. The design proposal allows for pedestrian access across the site, creating more connectivity from West DUMBO to East DUMBO. This will facilitate a greater connection between the disparate populations.

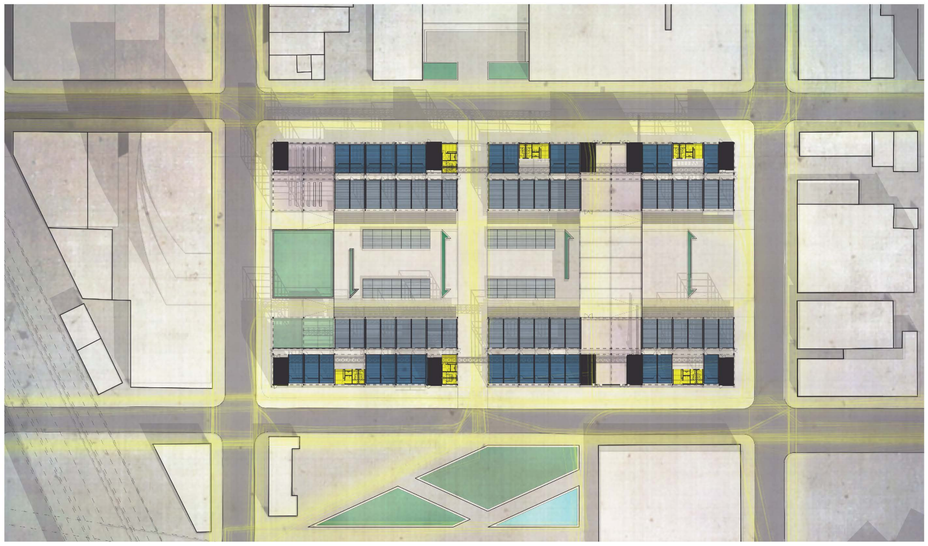

Figure 67: Phase 1, Site Plan

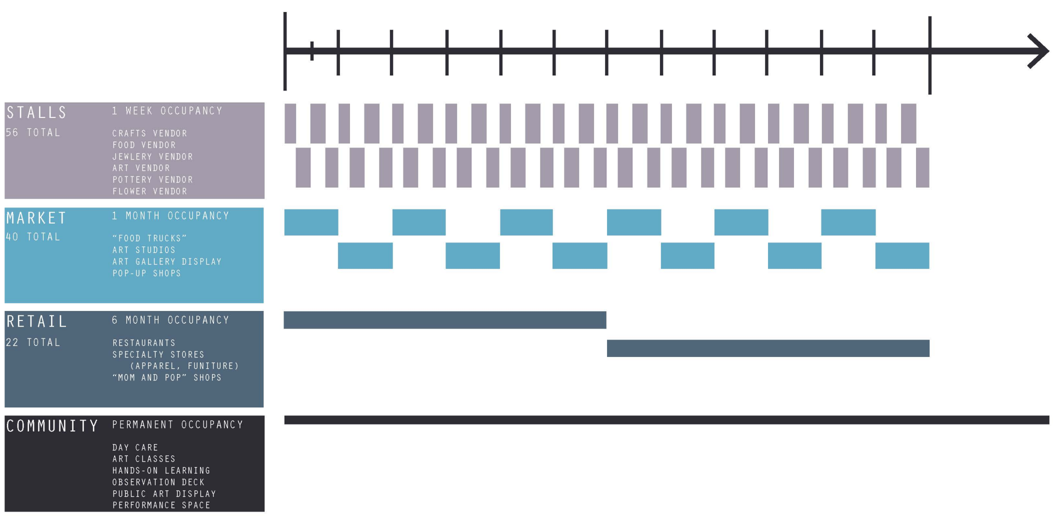

Figure 68: Occupancy

Figure 69: Neighborhood Divided

Figure 70: Neighborhood Merged

In addition to the everyday activities within the plaza, there will also be emergency hubs located throughout the ground floor. These hubs will include the necessary elements for a post disaster recovery. Within each is a fully equipped first aid station, an information station, storage with back up generators, restrooms, and charging stations. This will allow for a more seamless emergency recovery phase and more rapid assistance to those in need.

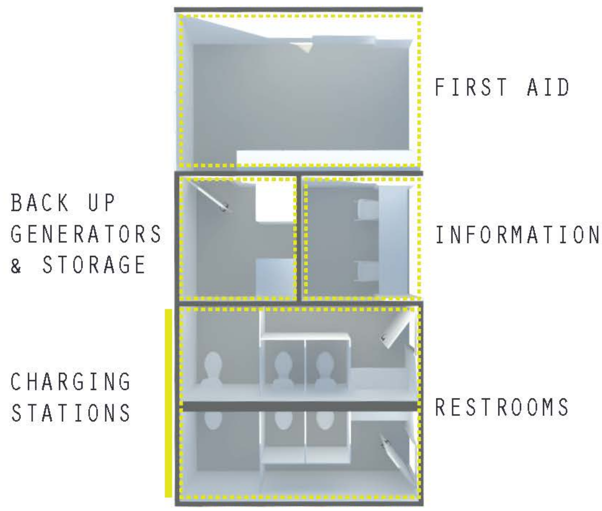

Figure 71: Emergency Hub

Multiple neighborhood events can now be held in this space, including the DUBMO arts festival, musical performances, and weekend markets. With the community spaces dispersed throughout the structural frame, visitors will have the opportunity to experience the frame and connections when travelling from one pod to another. This will act as a teaching experience about good building practices associated with preparing for seismic activity.

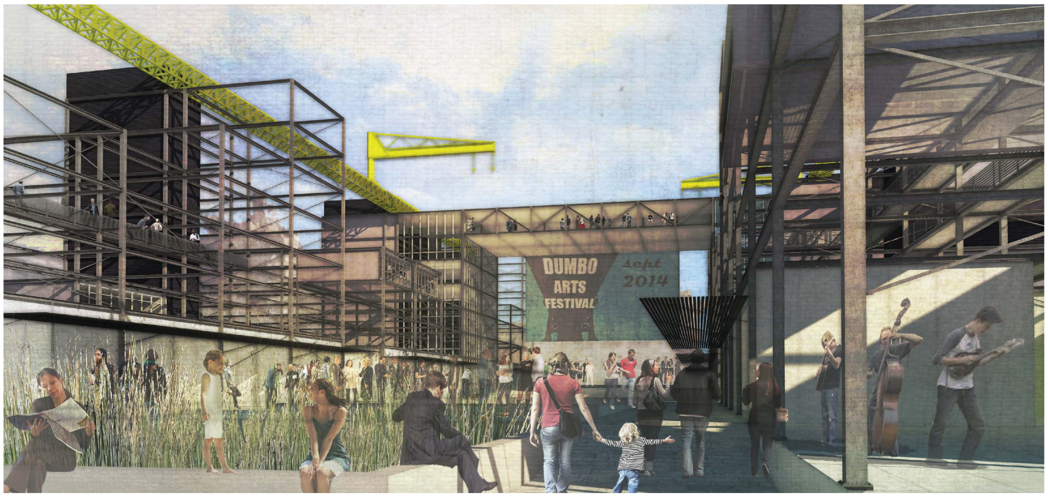

Figure 72: Phase 1, Plaza

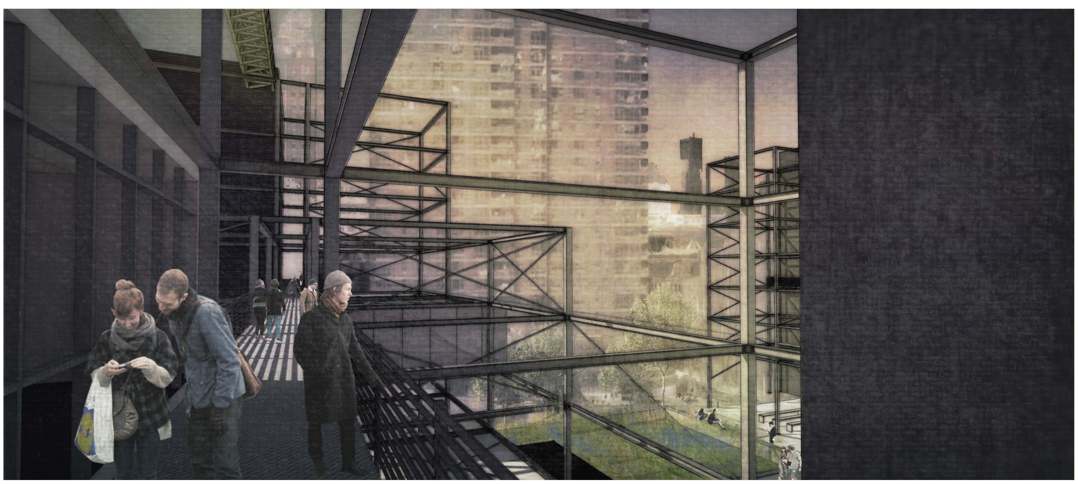

Figure 73: Phase 1, Community Pods

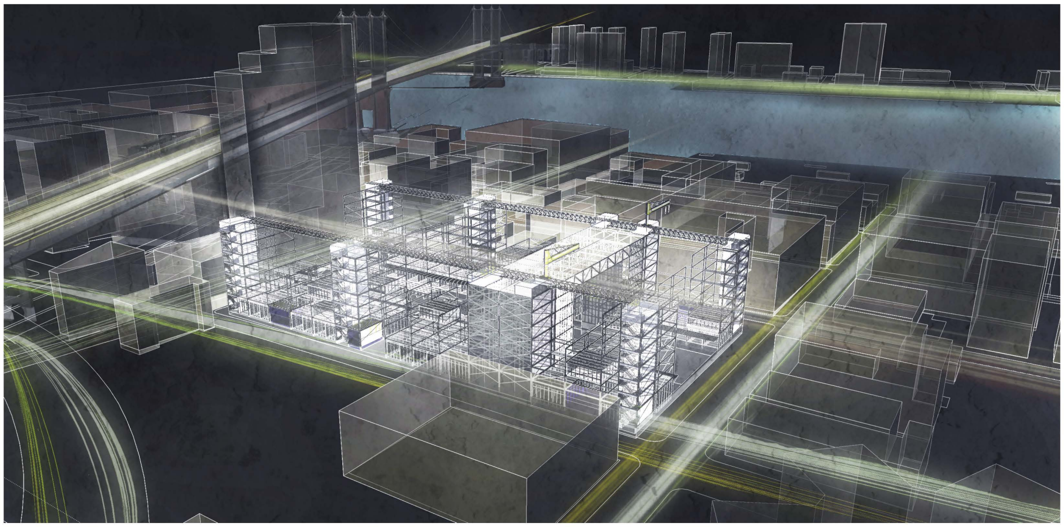

Figure 74: Phase 1, Night View

When a disaster occurs, the remainder of the frame will be completed, in order to prepare for the placement of the modules to create the emergency units. The modules will be quickly fabricated at the Brooklyn Navy Yard, producing 32 modules a day, resulting in the emergency units being completed and in place within 28 days after the disaster. These emergency units will provide the bare essentials for a family of four. Each unit contains a bathroom, small kitchen, dining space, and sleeping arrangements for four. To make this space as efficient and livable as possible, the unit is able to flex and change throughout the day for the needs of the residents.

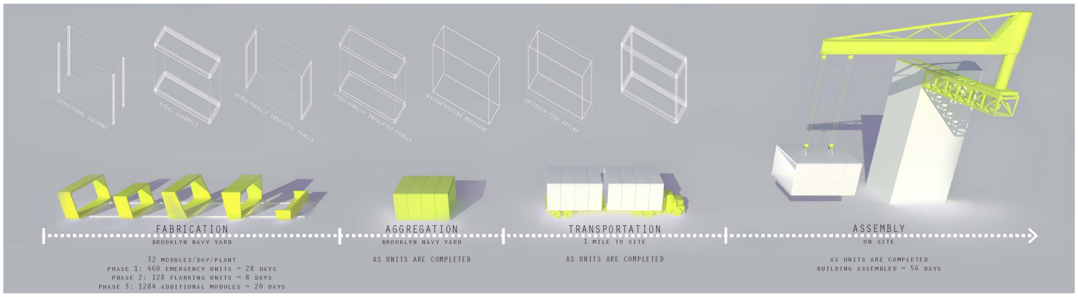

Figure 75: Assembly Process

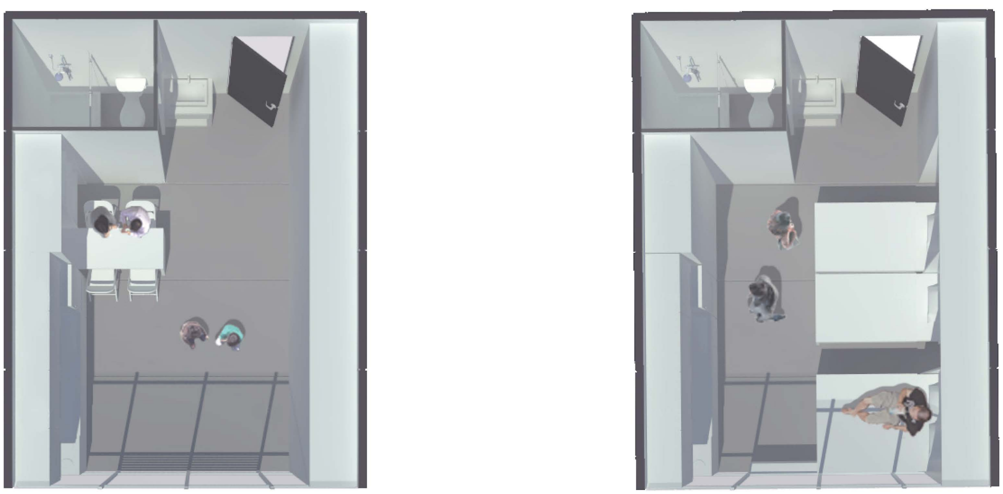

Figure 76: Emergency Units

Once all of the emergency units are in place, the units can be completed to form their final configurations. The crane will continue to drop the modules down into the frame to be connected with the emergency units. The final units will range from studios, to one bedroom and two bedroom options in order to accommodate a range of residents.

Figure 77: Relief to Recovery Phase

Figure 78: Recovery Units

Residents will have the opportunity to personalize their units as needed, as well as having the option to combine adjacent units. While some residents may stay here from the emergency phase through the recovery phase and even permanently, it is possible that after the disaster, these residents may return to their original homes and new tenants would have the opportunity to live within these units.

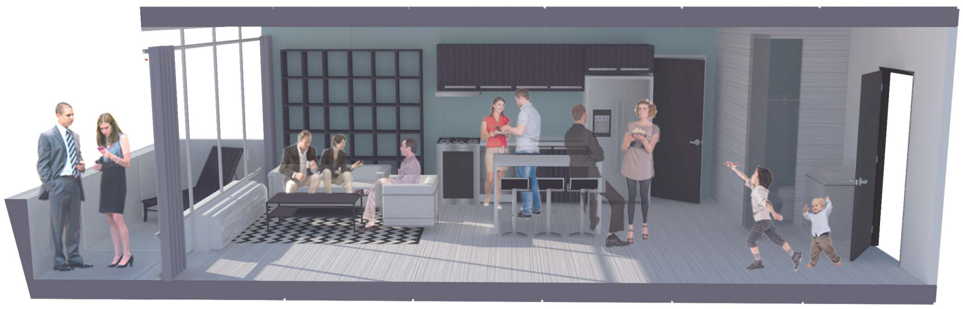

Figure 79: Recovery Unit

Figure 80: Phase 3, Final Building

Some of the jurors' comments included concerns about the public plaza once the private units were in place. The goal of this plaza is to remain public and within the supervision of municipal police to provide security. In addition, others were concerned with the dimensions of the modules. Currently, they are designed to be 15' by 5' by 11' for each module. These dimensions are within the trucking limits of the city; however, if the modules need to be transported further distances, the construction system could be utilized to create smaller scaled modules to perform the same function. Other jurors brought up the idea that these modules can be used for affordable housing developments, as well as disaster recovery communities. Finally, if time allowed, it would be important to design ways for renewable energy to be embedded into the initial design. This would allow for an off the grid development while the city utilities were being restored. Elements to include would be photovoltaic panels to provide the development with electricity and water collection and filtration systems to continue to provide water. Overall, the goals of this proposal were to design the disaster recovery before a disaster occurs, thus having the ability to be rapidly responsive to the needs of the community, as well as integrating into the neighborhood's future development goals.

Chapter 9: Conclusion

Due to the increase in occurrence of natural disasters, it is imperative for our society to learn to maintain resiliency, while also preparing for the aftermath of a disaster. In the event of a disaster, displacement occurs, thus disrupting the normalcy of the community residents. The major tasks of this proposal include providing emergency and permanent housing, within a condensed timeframe to a medium density while providing communal spaces and activities for long term use.

By finding an underutilized site in Brooklyn's industrial neighborhood of DUMBO, this thesis proposed an incremental development through phasing that would be implemented according to the occurrence of a natural disaster. The initial frame will be seismically resistant, as well as located outside the bounds of flood zones. If and when a disaster occurs, the frame would be used as the initial infrastructure to support an emergency and permanent residential community.
The frame will be filled with modules fabricated locally at the Brooklyn Navy Yard that would then be transported and placed into the frame through a crane system. This thesis proposes a solution to an existing community deficit, as well as providing a plan for the next natural disaster that will hit New York City.

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