ABSTRACT

Title of Thesis:	Revealing Risk & Redefining Development: Exploring Hurricane Impact on St. Croix, USVI
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This thesis explores the direct and indirect role of landscape architecture in disaster risk reduction specifically focusing on designing and managing natural resources such as sun, wind and water as well as allocating infrastructure to improve the power and transportation system on the public, private and regulatory levels that can prove to endure the impact of a hurricane and promote a "culture of prevention." Every year natural disasters cause a substantial amount of damage throughout the whole world bringing forward the importance of disaster risk reduction to prevent or to mitigate the adverse impacts of disasters. A two-step approach was formalized to develop an understanding and to produce a design proposal based on the practice and theories of landscape architecture. The findings from both steps will be applied to re-design the town of Christiansted, St. Croix, in the United States Virgin Islands.

REVEALING RISK & REDEFINING DEVELOPMENT:

EXPLORING HURRICANE IMPACT ON ST. CROIX, USVI

By

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Lastly, for the island that has given me so much, I give this to you.

TABLE OF CONTENTS

LIST OF FIGURES

Introduction

St. Croix

Every year thousands of people come and visit the United States Virgin Islands located in the heart of the Caribbean. Most marvel in the historic, architectural and economic charm that the local towns and people embody while taking in the wide range of sites the three islands have to offer. Those who have been to St. Croix have definitely experienced the main town of Christiansted either by car or on foot. Amidst the historic buildings and colorful flowers, people often forget about the natural disasters that frequently, often annually, wreak havoc on this town and island. In 2010, earthquakes, hurricanes and floods hit numerous countries across the globe, causing loss of life, suffering and large economic loss. The number of people affected by increasingly frequent hydrological events all over the world has doubled over the last 30 years.[1]

The contrasts between countries that have suffered a similar severity of hazard, but whose losses have been in orders of magnitude greater for lesser-developed countries, have shown that there is much work to be done in disaster risk reduction. Conceptualizing the effects of a natural disaster by viewing these along the timeline that begins with preparedness and ends with recovery is necessary. Envisioning this timeline as a repeating line, where events reoccur, may encourage increased focus on pre-disaster initiatives and longer-term thinking for response and recovery.

Methodology

The thesis includes a physical history of the site, documentation of existing conditions, an analysis and evaluation of landscape characteristics and associated

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[1] (R.A Pielke 2005).

features, and a multi-level guide to mitigate future destruction caused by hurricanes in Christiansted, St. Croix. It more fully documents the history of hurricanes that have affected the island, builds upon existing disaster relief processes, and evaluates landscape characteristics and features contributing to infrastructure failures within the site. In addition to the existing historic district of Christiansted, this thesis also addresses the surrounding landscape of the island that can be utilized for Caribbean wide disaster relief efforts.

The thesis will first focus on the various impacts hurricanes have had and explain the literature on disaster management. The next section is on disaster risk reduction practices where relevant literature has been explored of disaster risk reduction and the history of recovery typical throughout the world. This history is then compared to the specific history and analysis of St. Croix's personal recovery; focusing on St. Croix and the evolution that this landscape has gone through in order to understand how current and future development might impact disaster recovery. Following this, a detailed look at alternative energy practices that can be woven through the landscape help to develop the form and theme later used in the specific site designs. The final section synthesizes all the findings to provide St. Croix with a comprehensive plan and new design proposal for Christiansted that can be implemented to help protect the island from the threat of hurricane destruction.

This thesis is based on a review of existing literature in order to explore disaster reduction in the built environment. Academic literature, conference papers, journal and have been used for the review of hurricane impacts on a wide range of locations. The research portion of this thesis has been developed from the following three main papers:

“United Nations International strategy for Disaster Reduction Annual Report” (2010-201), “FEMA Strategic Plan” (2008-2013), and the “St. Croix Emergency Management Plan” (2011). Research has been undertaken at a thorough level of investigation, involving studying primary holdings at the VITEMA Headquarters on St. Thomas (USVI), at the National Archives in Washington, D.C. and at the University of Maryland in College Park, Maryland. Primary and secondary sources such as photographs, aerial images, textual descriptions and land use documents were examined to gain in-depth information regarding the physical development of Christiansted, as well as its significance in the islands history.

Research included examining all available documentation dating from early settle3rment of the local area through present-day. Of the available documentation, the majority of information found focused on the four most recent decades (1980 – Present) and the Danish rule over the island. While research uncovered sources that provided information for the pre-1980 era, a lack of specificity within the documents has made many findings inconclusive specifically in relation to weather intensity.

For this reason, the in-between history section relies heavily on secondary sources and predictions. In order to develop a complete understanding of the site, a combination of methods was employed. Historic photographs and maps were examined and compared to determine what changes occurred in the landscape throughout different periods of history. Field inspections were conducted to determine the existing features in the landscape and to identify what fragments might remain from earlier periods. Also, consultations with knowledgeable individuals, including park staff and architectural historians helped inform the understanding of the landscape’s evolution.

Chapter 1: Literature Review

There is an urgent need in the fields of disaster management for a comprehensive understanding of how to build resilient communities. This literature review examines the current practices and definitions of disaster management to present a basic knowledge of how government and communities react to disasters and constructs a framework for assessing community resilience and planning. An interdisciplinary body of speculative and policy-oriented literature is studied to provide a focus that is expanded beyond the physical to address all elements of society that are affected.

This literature review analyses key findings and studies issues that are not fully addressed by the current disaster recovery literature. It will first define the terms "disaster" and "disaster management" to gain the basic groundwork needed to understand the overall process. Once the definition of these words has been clarified, the dialogue surrounding them can be studied and directly applied to their relationship within the cultural and built environments. Past assumptions and research about the process that communities build both before and after a disaster are reviewed. A conceptual model for understanding disaster recovery efforts is then presented. Finally, conclusions on the practices of current disaster planning is summarized a series of guidelines are presented to move forward with.

1.1 Definition of Disaster and Disaster Management

"Disaster" is derived from the Latin word of *astrum,* meaning star.[2] In ancient times, it was believed that earthquakes, volcanoes, etc.. were mandated by the heavens. In today's world, nature is still something that we, as humans, have no control over.

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[2] (Dictionary.com n.d.)

However, we are beginning to understand how to change our environment in order to have a better control over their outcomes.

International Strategy for Disaster Reduction (IDSR 2002)[3] has defined disaster as a “serious disruption, of the functioning of a society, causing widespread human, material, or environmental losses, which exceed the ability of the affected society to cope using only its own resources”. Parker identified a disaster as “an unusual natural or man-made event, including an event caused by failure of technological systems, which temporarily overwhelms the response capacity of human communities, groups of individuals or natural environments and which causes massive damage, economic loss, disruption, injury, and/or loss of life”.[4] The World Health Organization defines it as “a sudden ecologic phenomenon of sufficient magnitude to require external assistance.”[5] No matter how disasters are defined they always encompass this overwhelming link to their effect on people.

Disasters are divided into two basic groups: natural and man-made. Among the natural disasters are hurricanes, floods, earthquakes, volcanoes, and fires. The man-made disasters can be anything from war, fires, transportation accidents, to hazardous materials exposures, and explosions. After the fall of the Soviet Union, The World Health Organization used the term “complex humanitarian disaster” to reference types of

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[3] (ISDR 2002)

[4] (Parker 1992)

[5] (Defining disaster: the emergency department perspective n.d.)

specific man-mad disasters: “a combination of civil strife and conflict leading to a mass exodus of people and the events that follow such as disease and destruction of property.”[6]

We tend to think of disasters as acute situations, but they can also be chronic. It took over 30 years of the chronic pollution in Love Canal for it to be constituted a disaster. Worldwide, a natural disasters needing international assistance occur weekly, and a major disaster occurs daily.[7] For the last 20 years around $50 billion in property losses and 3 million lives have been taken from disasters. The risk will increase in years to come with more people moving into disaster-prone areas. Disasters are not isolated events, but happen again and again. Physical losses are an essential element of a disaster with the ramifications spreading to cultural, economic, social, and institutional sectors.

1.2 Natural Disaster Framework

Tufekci and Wallace suggest that emergency response efforts can be portrayed in two parts; pre-event and post-event.[8] Viewing disaster recovery as pre-event planning and post-event actions provides another way to frame the idea of resilience and sustainability. Pre-event procedures include assessing the threats and developing a mitigation plan. Post-event response starts while the disaster is still in progress. Tufekci and Wallace also suggest that “an effective emergency response plan should integrate both of these stages

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[6] (Defining disaster: the emergency department perspective n.d.)

[7] (Heide 1996)

[8] (T. a. Wallace 1998)

within its objective."[9] Without this collaboration the most favorable recovery outcome cannot be achieved.

America's comprehensive emergency management is typically broken down into four programmatic phases: mitigation, preparedness, response, and recovery[10]. The four-phase approach covers all of the actions described in Tufekci and Wallace's classification while providing a more focused view of emergency management actions. These classifications are based on the Comprehensive Emergency Management concept of 1978 which laid out the National Governors' Association Emergency Preparedness Project. Figure 1 shows the schematic diagram of disaster emergency management as designated by Kawata.

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[9] (T. a. Wallace 1998)

[10] (Kawata 2001)

Figure 1: Disaster Management Cycle[Kawata]

Response is the allocation of resources and emergency procedures as guided by plans to preserve life, the environment, property and the social, political and economic structure of the community. Recovery is the long term actions taken after the immediate impact of the disaster has passed to stabilize the community and bring it back to normalcy. Preparedness actions are implemented prior to the disaster so that the community can better respond when a disaster does, in fact, occur. Mitigation is the use of measures to reduce the impacts or prevent the onset of a disaster should one occur.

1.3 Disaster in the Cultural & Built Environment

"Much of the physical damage from disasters occurs to infrastructure and therefore engineers and landscape architects have a vital role in the rectification of physical damages of disasters."[11] Landscape architects can contribute to mitigation measures including enhancing building/ street/ land codes, standards, new material recommendations, and construction technologies in hazard and risk areas by teaming with suppliers, institutions and authorities.[12] Landscape architecture professionals have a vital role in all phases of the disaster management cycle portrayed in Figure 1 above. It is important to be aware of the conditions of built environment in order to propose improvements that reduce disaster risk.

The built environment is a term used to describe the products of human building activity.[13] Some have further expanded the definition to include any changes of the natural environment through construction by humans. Below one author, Bartuska[14], has identified four main characteristics of built environment.

1. Humans have formed their surrounding built environment to be acutely functional to satisfy the everyday needs and want to maintain their desired lifestyle. Haigh and Amaratunga state that the "built environment provides the context for all human endeavors."[15] Therefore, once a disaster strikes, elements of their environment can be damaged or destroyed which would hinder the function of society both economically and socially.

2. Second, the built environment is erected according the wants, needs and values of the people who function within their space on a daily bases. A disruption to this process

[11] (Ofori 2004)

[12] (Y. Chang 2010)

[13] (Low 1990)

[14] (Bartuska 2007)

[15] (Amaratunga 2010)

of moving forward as a society with new or updated buildings, roads, etc.. can hinder the overall psyche of a nation and set them back both emotionally and economically.

3. Built environments are constructed to help prevent the risk of disasters. By having this proactive stance we are identifying the potential risks and mitigating them, to the best of our ability, before they become a problem.

4. Lastly, each component of the built environment is shaped by the context that surrounds it. The history, people, culture and future all have an impact on how specific places are constructed and react to different variables. This point does not allow generic solutions to problems and instead offers an opportunity for landscape architects and engineers to develop place specific guidelines for mitigation and reconstruction.

According to Kibert[16] "the academics and professionals in planning, civil engineering, economics, ecology, architecture, landscape architecture, construction and related fields are responsible for discovering ways of creating a more sustainable built environment." There is clearly a high relationship between the designing for disasters and the built environment disciplines.

1.4 Disaster Risk Reduction in the Built Environment

Landscape architects play a major role in disaster risk reduction. Two categories can be singled out to describe the role played by the construction industry in disaster risk reduction: the role in pre-planning for a disaster and also in the wake of a disaster during the recovery phase.

1.4.1 Pre Disaster Protection Phase

In the pre disaster protection phase, landscape architects are required to design for the anticipation and mitigation of large and small scale destruction. These include sea

[16] (Kibert 1999)

walls, drainage systems and infrastructure, and advising about building regulations and codes, land use planning and zoning requirements.

Haigh and Amaratunga[17] stressed the role that infrastructure can have after the impact of a disaster particularly when the quality is not sufficient. Oh et al[18], too supported the argument stating “with proper planning, the impact of natural disasters can be reduced and that it is necessary to identify critical infrastructure that are vulnerable to natural disasters and the necessity of taking appropriate rehabilitation measures”. These authors support the argument that landscape architects have a vital role in pre disaster protection and risk reduction of disaster management.

According to ISDR (2010) “the local governments can play a major role in urban disaster risk reduction.” [19] The role of the government is such a huge component because they have direct control over things such as public works, land use planning, social services and directly being responsible for its constituents. Local governments should consult with landscape architects in order to perform these activities effectively. Additionally, ISDR (2010) has identified the specific risk reducing measures in which professionals in the field can interact with local governments. This includes: “invest and maintain risk reducing infrastructure such as flood drainage; apply risk compliant building regulations and land use planning norms appropriate to the needs and possibilities of low income citizens; ensure the safety of all schools and health facilities and upgrade as necessary; provide ecosystems and natural buffers to mitigate floods,

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[17] (Amaratunga 2010)

[18] (E. Oh 2010)

[19] (Reduction 2010)

storm surges and other hazards; and adapt to climate change building on risk reduction practices”.[20]

1.4.2 Post Disaster Recovery

The post disaster recovery involves two phases: Recovery and Reconstruction and Emergency Response and Relief,.[21] In both these phases, the design industry plays a major role mainly in terms of reconstruction work.

The Emergency Response and Relief phase focuses on transport of clean water and sanitation to victims, construct temporary shelters, and the reconstruction of damaged infrastructure such as bridges, roads, electricity and telephone lines as well as material supply. Being able to have a critical understanding of not only the engineered perspective but also the cultural and social makes landscape architects invaluable when re-building a destroyed location.

During the Recovery and Reconstruction phase all major changes are implemented. Design changes to both public and private infrastructure such as housing, education and health are all taken into consideration and appropriate modified to have a more resilient future outcome. According to Keraminiyage et al., “the construction industry has a much broader role to anticipate, assess, prevent, prepare, respond and recover from disruptive challenges in the case of post disaster recovery.”[22] The process for this reconstruction work does not begin after the disaster hits however, most

[20] (Reduction 2010)

[21] (Reduction 2010)

[22] (KERAMINIYAGE 2007)

reconstruction work should be planned well in advance in order to avoid future vulnerabilities.

1.5 Conclusions

The built environment was created for the human and shaped around cultural cues, everyday necessities as well necessary protective measures all to keep them safe and happy. However, when a disaster strikes and collapses that system it can completely topple a society. According to Ofori, "it is necessary to provide the construction industries in developing countries with the requisite capacity and capability to enable them to plan, design and build constructed items to reduce their vulnerability to disasters, and to respond effectively to disasters that save and protect lives, rehabilitate vital infrastructure, and reinstate economic activities."[23] The success of recovery can be enhanced by the establishment of a set of plans prior to a disaster for coordinated post-disaster recovery planning and implementation. This literature review discusses the role of the landscape architects throughout all of the planning process that goes into preparing for a natural disaster. Both the pre and post-disaster phase hold importance when planning because of the varying but instrumental role in the recovery of a place.

[23] (Ofori 2004)

Chapter 2: A History of Recovery

2.1 History of St. Croix

St. Croix is an island found in the Caribbean Sea, and the largest of three unincorporated Islands that are part of the United States. The Virgin Islands of the United States consist of St. Thomas, St. John and St. Croix, and these three islands are about 135 square miles and have a population not exceeding a quarter of a million people. This comprises about 75 percent African descent, 13 percent U.S. mainland expatriates, 5 percent Puerto Ricans, and the rest are a mix of Danish, French and people from the Caribbean. St. Croix is seven by 28 square miles (45 by 11 km) and is the largest of the U.S. Virgin Islands. Charlotte Amalie, which is the capital of the territory, is located on Saint Thomas. [24]

The people who originally settled in the Virgin Islands include the Ciboney, Carib and Arawaks peoples. For the period towards 17th century, these islands were conquered and controlled by many European powers, including the Netherlands, France, the United Kingdom, Denmark and Spain. While the Danish West India Company was expanding their influence into the Caribbean Sea in 1767, they built settlements on St. Thomas and St. John. However in 1773, Denmark purchased St. Croix from France and proceeded to transform the islands into royal Danish colonies by 1754. Soon thereafter, due to the work and effort of slave labor, the sugarcane business began to prosper.[25] The economy continued to blossom across the island around those years. However, with the abolition of slavery in the middle of the 19th century, "free labor" was hard to find. For this reason,

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[24] (National Register of Christiansted St.Croix n.d.)

[25] (National Register of Christiansted St.Croix n.d.)

the Virgin Islands became unprofitable very quickly. The Danish government tried to sell the islands to the United States, a move which was unsuccessful. But since it was during World War I, the United States was concerned that the Germans would possibly use the islands as a submarine base, and hence offered Denmark $25 million for the islands. Denmark agreed to this deal and signed it on January 17, 1917. The United States took official possession of these islands on March 31, 1917 and renamed them "The Virgin Islands of the United States." The inhabitants of the island were granted U.S. citizenship ten years after this takeover.

2.2 Hurricane Activity of St. Croix

The major concern with the weather in St. Croix is the hurricanes. The season for these Hurricanes runs from July to November every year and most tourists plan their getaways to these islands accordingly since temperatures are almost constant throughout the year. Updates and information about the weather and other environmental concerns can always be accessed from the National Hurricane Center.

2.3 Virgin Islands History of Disaster

Some of the most severe disasters the U.S. Virgin Islands has experiences are listed below:

Hurricane Hugo (1989) -On September 18, 1989, Hurricane Hugo happened on the island of St. Croix as a category four storm. Hurricane Hugo had winds of 140 mph (230 km/h) and created a 2-3 ft. storm surge. Two people were killed as a result of the storm with an additional 80 people being injured. Ninety percent of the buildings on the island were either destroyed or damaged. All infrastructure was destroyed including hospitals, power lines, banks, and telephone lines. The island of St. Croix was unable to function. In the days after Hurricane Hugo's impact there was wide spread looting which required the territorial governor to request federal assistance from the President of the United States (George H.W. Bush was currently in office during this event). For a two month period Army military police enforced a dusk to dawn curfew and patrolled the island. In combination with other US owned Caribbean islands, damage estimates were around $1 billion dollars.

Hurricane Bertha (1996) – The final calculation of rainfall on the island of St. Croix totaled at a maximum of 3.28 inches while the winds generated by the storm were as high as 85 mph. There were 1,415 damaged homes where 43 of these lost their roofs. These statistics about the damages were provided by FEMA. An individual, who chose to ride out the storm on his sailboat was seriously injured. The damages caused by the storm were estimated to range around $7.5 million dollars.

Hurricane Georges (1998) –The rainfall totals were around 7 inches on St. Croix while St. Thomas only had around 5 inches. On St. Croix, the hurricane winds were ranging up to 74 mph with the maximum wind gusts being 91 mph. 50 homes on the island sustained damage and 20 were completely destroyed. The more serious losses caused by the storm were in the livestock and agriculture sector. Total losses were estimated to be $2 million dollars.

Hurricane Omar (2008) - Hurricane Omar produced rainfall totals of more than 7 inches and sustained winds of the storm were recorded to be 53 mph on the island of St. Croix. Ocean waves were as high as 15 feet and managed to sink 47 boats as a result. Majority of the island was left without power. An estimate of the destruction caused by the hurricane was around $700,000 dollars. An additional $1 million was incurred in clean-up costs.

2.4 St. Croix Personal History of Recovery

The U.S. Virgin Islands have a history of being hit by hurricanes, earthquakes, and flooding. The territory's disaster mitigation plan as primarily been aligned with addressing the damage caused by the destruction of hurricanes.[26] Should there be a natural disaster within the territory, formal procedures that outlines the protocols for a disaster declaration are in place. Directly after a major disaster, a state of emergency cane be declared by the territory's governor. Then, an assessment of damage throughout the islands and will be collected and submit to FEMA.[27] FEMA then provides this information to the president's office for decision about relief activities and funds.

The president of the United States initiates the action of federal assistance by declaring the territory a disaster area. Once the need for financial assistance is recognized the territory has the opportunity to apply for federal aid[28]. As noted by Bea et Al, "The declaration activates the disaster plan and response and recovery activities, and authorizes the deployment and use of any forces, supplies, equipment, and facilities."[29] FEMA will begin to provide funding resources and assistance.

There exists two tiers of disaster declaration depending on the extent of damage encountered within the territory. Aid may only be given to individual homeowners and small businesses or government agencies for community repair. Bea et al (2004, p. 4) states, "When financial assistance is essential to meet the needs of individuals or families after the President issues a major disaster declaration, the governor is authorized to accept a grant by the federal government or to enter into an agreement with the federal

[26] (Alperen 2006)

[27]Kossler, B. (2009). Disaster Agencies Outline Relief Programs. Saint John Source.

[28] (Bea 2004)

[29] (Bea 2004)

government to participate in funding. All federal grants and local matching funds are to be deposited in the general disaster relief fund (Virgin Islands Code, Title 23, Chapter 12, §1135). The "general disaster relief fund" within the treasury is used to meet necessary expenses or serious needs of individuals or families that cannot otherwise be met from other means. Grants of assistance cannot exceed $5,000 per family per incident. The fund consists of appropriations by the legislature and the proceeds of federal grants (Virgin Islands Code, Title 33, Chapter 111, §3041)."[30] Only a federal executive order can terminate the governor's emergency declaration once this assistance is no longer required,

2.5 Preparation Plans

The United States Virgin Islands has been cited as a community which is disaster resistant by FEMA.[31] FEMA's effort to move from a culture of reaction to one of avoidance can be seen through the implementation of the national Project Initiative. Through this program FEMA donated $300,000 dollars to the territory to complete preventative measures to ensure that the safety of their citizens was being addressed. According to Samuel, the funding that was allotted to the island of St. Croix has been used primarily to:

- "Conduct assessments of the structural integrity of one of the islands primary shelters and to correct deficiencies so as to allow it to better withstand earthquakes and

[30] (Bea 2004)

[31] (Staff 2011)

hurricanes, and to allow for the detection and identification of the most disaster-resilient facilities which also serve multi-hazard purposes;

- To sustain partnerships between the private sector and the public through the use of a small grant program which provides incentives for groups and communities to identify those areas of greatest risk and minimize damage by addressing mitigation strategies of greater priority (short-term and long-term mitigation measures which address preparedness needs have resulted due to partnerships between the government, homeowner associations, local businesses, and community organizations);
- To provide disaster mitigation education and awareness to the public with an island-wide educational campaign that has been enacted to develop a family disaster resource manual, a school-based curriculum to educate on family disaster planning, and the development of a best practice resource guide for construction builders."[32]

Due to unprecedented damage of Hurricane Hugo for instance, the Virgin Islands government implemented the enforcement of new building codes that would require buildings and structures to withstand the winds of a category two storm. The new code required the use of hurricane clips, anchoring systems, and shutters on buildings.[33]

After the impact of hurricane Bertha, in 1996, the governor's office began a home protection roofing program to repair damaged roofs.[34] Nearly 350 residential homeowners were built to withstand a category 2-3 hurricane. Of course, "designing buildings to withstand a Category 2 storm or 110 mph winds will not protect the island in

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[32] (C. Samuel 2009)

[33] (FEMA 2007)

[34] (Building Better n.d.)

the event of a higher-level storm, but it will prevent major damage in 87 percent of the storms."[35] Much of the infrastructure has been retrofitted or rebuilt before subsequent disasters, and since then, there had been damage to less than 2 percent of the private homes. Currently, all building code regulations are overseen by the Division of Building Permits, which is a division of the U. S. Virgin Islands, Department of Planning and Natural Resources.

Electrical distribution systems were another undertaking implemented after past hurricanes. Power is essential for the territory to begin the recovery and reconstruction process after a large hurricane. After the impact of Hurricane Hugo (1989) and Hurricane Berthas (1996), there was a complete failure of the power system on all three Virgin Islands.

Funding from the hazard mitigation grant program and public assistance was able to be used towards multiple projects such as "burying power poles foundations to proper depths, instituting procedures to ensure that poles did not become overloaded with power surges, running an underwater cable from St. Thomas to St. John to ensure that power remained on the island, building new substations to decentralize the power grid, and enclosing distribution facilities to ensure power production".[36] As a result of these changes, in 1998 after Hurricane Georges, there was power interruption to only 15% of St. Croix and full restoration was accomplished in three weeks.[37]

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[35] (Building Better n.d.)

[36] (Building Better n.d.)

[37] (Building Better n.d.)

In 2000, FEMA's hazard mitigation program primarily funded one of the largest projects WAPA has undertaken in the territory.[38] The project focused on burring electrical lines and feeders underground to critical locations such as hospitals and airports. In 2009 WAPA took several steps to prepare for hurricane season including borrowing $5 million dollars to purchase 90,000 barrels of extra fuel in order to fill their reserve storage tanks to capacity. [39] This solution dealt with the issue of having additional amounts of fuel on hand after a disaster.

According to Steve Parris,[40] the former Deputy Director of VITEMA-St. Thomas, VITEMA took steps to develop a new disaster mitigation plan that was in response to the 2002 2002 Disaster Mitigation Act that addressed hurricanes, earthquakes, tsunamis, and floods. The disaster mitigation plan was developed with help from several consultant firms. According to Mark Walters, "other mitigation projects that have recently been undertaken by VITEMA include ensuring that hurricane window shutters have been installed on buildings deemed as critical facilities (emergency shelters and hospitals) and carrying out road projects to install flood alleviating drainage culverts". [41]
The former director of VITEMA advised the territory's legislature that VITEMA will require $12,714,948 dollars for fiscal year in efforts to better mitigate future disasters.[42] The intended use of the funding is to carry mitigation efforts such as burying electrical cables to important facilities to improve the recovery time following a disaster.

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[38] (Bate 2000)

[39] (Pancham 2009)

[40] (Shimel 2004)

[41] (VITEMA 2010)

[42] (VITEMA 2010)

2.6 Conclusions

A review of the pertinent literature discusses two distinct parts of disaster mitigation and planning: pre disaster protection and post disaster recovery. After reviewing at the history of response and recovery on St. Croix, it is clear that St. Croix is requires significant work to achieve either of these vital components. Alperen asserts "U.S. Virgin Islands is a collection of unassimilated and isolated groups that have their own respective non-mingling social circles and differing family, household, occupational, labor force, income, and educational characteristics, are often residentially segregated, and engage in widely disparate and exclusive recreational and associational activities."[43] The disparities among social groups are also reflected in the territory's government. Consequently VITEMA (Virgin Islands Territorial Emergency Management Agency) does not regularly exchange ideas with the local rescue squads. The V.I. Department of Homeland Security is not accessible to the population. The V.I. government needs to be more networked, seamless and integrated."[44] The lack of cohesion throughout the community and government is evident and a unifying plan to move forward with is needed.

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[43] (Alperen 2006)

[44] (Alperen 2006)

Chapter 3: Site Analysis

3.1 Economic

Economic and social change has been rapid in recent years and Virgin Islanders have found it increasingly difficult to preserve their rich heritage. The variegated racial and national groups in the society today reflect the waves of immigration. St. Croix was once known for her agricultural productivity in the Caribbean ending the rapid industrialization in the island in the 1960s. here tourism is one of the main sources of revenue, like it is in many other Caribbean islands presently. However, the island has a number of other industries to help support her economy.

St. Croix hosted HOVENSA, which is one of the largest oil refineries in the world, was permanently closed in January of 2012. This sudden announcement is currently having a major impact on St. Croix and the U.S. Virgin Islands community in general, since the refinery employs around 3,000 workers and provided the government with a large source of income.

The Cruzan Rum Distillery, which makes Cruzan Rum and other liquors such as Southern Comfort, is also found in St. Croix. Having been founded in 1760, The Cruzan Rum Distillery has for many years used local raw material, sugar-cane, to produce single barrel dark rum. Currently, the distillery imports sugar cane molasses from other islands around it, mostly from the Dominican Republic.

3.2 Topography

The US Virgin Islands consist of three islands with the majority of the total land area being on St. Croix at 88 square miles in size. St. Croix is situated 40 miles south of St. Thomas. It is the easternmost point of the United States (Point Udall). Christiansted (population of 3,000 in 2004) and Frederisksted (population of 83 in 2004) are the two major towns on St. Croix. The total island population is approximately 60,000 people and is separated into nine sub districts.

The eastern side and north side of St. Croix has a hilly and moderately steep geography. Mount Eagle and Blue Mountain are the two tallest peaks, both reaching nearly 2,000 ft.,[45] and are located on in the northern region of the island. The southern side of the island is mostly flat and contains many lagoons near the coastline.

Christiansted and Fredricksted both lie on flat portions of the islands. Six percent of the territory's total land is forested and farmland constitutes roughly one-fifth of the territory's total land area. Mahogany trees have been planted by the government in the efforts to reforest the island. The lack of water and irrigation to St.Croix's rivulets has been a large source of issues for both farmers and non-farmers. Numerous dams were built in order to improve water supply and irrigation however, they have been poorly maintained and have since fallen into disrepair.

3.3 Climate

The U.S. Virgin Islands have a temperature average of 78°F in the summer and 71°F in the winter with gentle trade winds, low humidity and little pollen.[46] The direst months fall between February and March while the wettest fall between September and November. The average rainfall total is between 45 to 50 inches per year.[47]

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[45] (C. Samuel 2009)

[46] (C. Samuel 2009)

[47] (Zack 1994)

3.4 Water

The frequent occurrence of droughts in the U.S. Virgin Islands is typically severe due to a limited amount of ground water supplier. Depletion in rainfall impacts the territory's agriculture and requires residents to ration the water supplies. Because of this many residential homes have their own cisterns or wells. Thirteen percent of the fresh water is obtained from rainfall corralled by rooftop catchments and 22% of the freshwater supply is obtained from ground water. With periods of droughts being to frequent, alternative means for supplying fresh water is needed. Sixty five percent of freshwater supplies in the U.S. Virgin Islands are supplied by desalinated sea water. Because the water needs to be desalinated the cost of getting fuel for the desalination process to the island is factored into the total price per liter. This need for external resources has propelled the Virgin Islands to the top of the list in the United States for having the most expensive water per liter. Established in 1965, the Virgin Islands Water and Power Authority (WAPA) operates several desalination plants.

The source of much of the flooding on the island of St. Croix is caused by insufficient drainage systems throughout the island. According to Island Resources Foundation, "floods in the Virgin Islands derive from three potential sources: 1) rain, which creates what we will call "inland flooding" in this plan, even though much inland flooding occurs on the coast; 2) sea surge from hurricanes or wind driven waves; and 3) tsunamis." [48]

Former Senator Bent Lawaetz states, "In the 1960s to the 1980s, the Department of Agriculture built 130 ponds on St. Croix and several dozen on St. Thomas as part of a

[48] (VITEMA Flood Hazard Mitigation Plan. 2010)

special USDA program"[49]. As aforementioned, these water catchment areas require frequent maintenance in order to be effective, however maintenance has ceased. The 2004 edition of the Territorial Hazard Mitigation Plan goes into detail on these flooding hazards however, does not lay out a plan to avoid future flooding issues. Important facilities such as a desalination plant, the main power plant and one police station are located in areas that are prone to flooding.[50]

3.5 Plant Life

Both urban and rural trees in the USVI are subject to the extremes of nature, especially tropical storms and hurricanes. Urban trees are especially susceptible to these storms. During and after a storm event, many urban trees become hazards as branches break and fall on vehicles, or across wires or roads. The antiquated sewer system in Christiansted is susceptible to clogging because of tree debris, thus providing an even greater need to monitor the health of trees preventing them from becoming hazards during and after a storm.

3.6 City of Christiansted

Christiansted has a population of around 3, 000 and is a former capital of the Danish West Indies.[51] To this day the 18th-century Danish-style buildings, built by African slaves, can be seen in pastel colors with brightly colored tile roofs throughout the city. Christiansted reflects the 18th century European architectural style that was so prevalent during its rise to becoming a large port city. The construction of Christiansted we primarily done by African slaves and the subtle influences define it as one of the few

[49] (VITEMA Flood Hazard Mitigation Plan. 2010)

[50] (Alperen 2006)

[51] (C. Samuel 2009)

"African-Danish" towns in the world. The town's grid system makes it popular for walking tours with streets running at ninety degree angles to the waterfront. The commercial areas can be found centrally located along King and Company Street. The residential area extends inland from the commercial area. Because of the tourism industry the town has several small hotels, scuba shops and restaurants to cater to the commercial industry. The wharf provides easy access to many diving locations on the island.

Covering nearly 30 acres, this site contains five classic Danish Colonial buildings open to visitors:

1. Fort Christiansvaern: Erected in 1749 and enlarged around 1835 it was originally built to protect the town from attack and to enforce collection of customs duties. It also housed troops to prevent slave revolts and to defend the port.

Figure 2: Map of Christiansted grid layout [Abraham]

2. The Steeple Building: In 1751, this was originally the first Lutheran church on St Croix. The building was later used as a school, a storehouse, a hospital, and at one point a bakery.

3. The Old Danish Scale House: This is place where giant barrels were filled with sugar and weighed before exportation. As you enter the building the huge scales seen were also used to weigh imports. The building is now used as the Visitors' Bureau and National Park Service Information Center.

Figure 3: Panoramic view of the Scale & Customs House [Abraham]

4. The Customs House: Adjacent to the Scale House the customs house is where taxes were paid on imports and exports passing

5. The Danish West India and Guinea Company Warehouse: Previous the headquarters for the Danish West India Company, originally three times larger than the current structure. The cultural history is complex because its courtyard was the site for some of the biggest slave auctions in the Caribbean.

Chapter 4: "The Green Island"

4.1 USVI Energy Background

Island communities everywhere are looking towards alternative to fossil fuels because of abundant renewable energy resources. The U.S. Virgin Islands has set ambitious targets to reduce oil consumption and has lead the effort to reduce oil imports and to aid in the energy crisis currently plaguing the island through renewable energy technology. This chapter provides a framework within which decisions and a guide can be made to determine what questions should follow.

"Developing and advanced economy relies on secure, affordable energy for economic growth and prosperity."[52] Island communities face challenges with access and development of energy systems because of their secluded nature. Access to affordable, secure sources of energy for economic, environmental, and social development is necessary for the future of their nation. "They typically have few conventional energy resources (i.e., oil, natural gas, and coal), and their remoteness and relatively small size lead to diseconomies of scale."[53]

4.2 Developing a Strategic Energy Road Map

A basic feasibility assessment was conducted to determine what energy technologies were advanced enough to be installed and possibility both financially and maintenance wise that they would endure the test of time. The feasibility assessment attempted to cover the following issues:

1. Economic viability..

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[52] (UN 2011)

[53] (Weisser 2004)

2. Availability of resources
3. Land constraints.
4. Technology maturity

Preliminary assessments from an industry consultant indicated that there were many energy efficiency opportunities in the residential sector as well as among large commercial and industrial consumers. "Reductions in end-use consumption on the order of 20 to 40 percent have been estimated across end-user types."[54] On the supply-side, a 22% increase in power system efficiency could be obtained if the USVI Water and Power Authority's current operation was overhauled with different, sustainable, practices. [55] Wind power solar photovoltaics, and solar water heating (SWH) are resource abundant in the USVI. However, it is also the highest-cost renewable energy technology, "solar PV capacity ranges from only 6 MW to 13 MW, with the majority of this being utility-scale PV installations".[56].

4.3 Three Energy Scenarios

This section outlines three energy scenarios (base case, high energy efficiency, and renewable energy) as possible roads to achieve the 60x25 goal. They combine a mixture of private and public partnerships at different degrees of participation all aimed at reducing the fuel consumption of St. Croix.

The "base case" scenario is the most likely outcome to achieve the 60x25 goal. The scenario is a balanced, but aggressive, mix of renewable end-user efficiency and

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[54] (Beck 2010)

[55] (Beck 2010)

[56] (Weisser 2004)

supply-side efficiency. Some energy installations are currently being built in the Virgin Islands to become incorporated into the current energy grid.

The high efficiency scenario looks that the impact that an extremely aggressive, both financially and technology wise, energy system could have on the efficiency of the current energy grid. Basically, it takes the base case and applies a much higher dose of the infrastructure associated with the base case. A balance between energy efficiency and renewable energy is envisioned in the high efficiency case. Due to its relative cost effectiveness, deployment of energy efficiency measures could have a lower cost than the base case.

Potential for an aggressive energy scenario does exist to achieve the 60x25 goal. However, the difficulty associated with such a dramatic change in 25 to 50 percent of end-user electricity consumption would be difficult to impose on the residents. The alternative would be building a renewable generation system.

The three scenarios portrayed vary principally in cost and the mix of equipment needed to reach their desired outcomes. However, in any of the cases, the outcome of reaching the 60x25 goal would mean so much for this small island nation. More than $100 million annually would be conserved if these scenarios can be implemented.[57] While St. Croix has taken a step in the right direction by implementing this 60x25 ruling, taking the steps to fully implement this level of efficiency will be monumental and require a lot of input from residents, private investors, and the government sector.

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[57] (K., et al. 2011)

4.3.1 Base Case

The case states that 43% of the energy efficiency needs on St. Croix will be met by upgrades to the supply-side sector. As stated many efforts are currently underway, however the full implementation of advanced technology and appropriate materials is necessary to be able to see any of these efforts come to fruition. Solar water heating systems are aimed at holding about 40% of the new energy input and account for the largest renewable technology contributing. End-user energy efficiency constitutes about 13 % of the total.

Regarding the monetary aspect, the Virgin Islands has a very limited budget so the implementation of all components needs to be handled with a high degree of thought. "To implement the full portfolio of capital and infrastructure improvements associated with this scenario, it is estimated to cost about $565 million."[58] Naturally the more advanced the technology is the more costly it becomes so larger contributors to the 2025 energy mix tend to be the higher priced options. Solar Hot Water systems totals about $70 million and solar PV (utility- scale and distributed) is estimated to be about $62 million.[59]

4.3.2 Solar Technology

Because of its proximity to the equator the sun in most parts of the Caribbean can be extremely strong. The abundance of solar resources can prove to be very useful in reaching the 60x25 goal by utilizing solar power as a key source of energy. The solar maps below shows the amount of daily sun in particular points on the map and provides an guidebook as to where to utilize solar PV to gain the best outcome.

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[58] (VIBER 2011)

[59] (VIBER 2011)

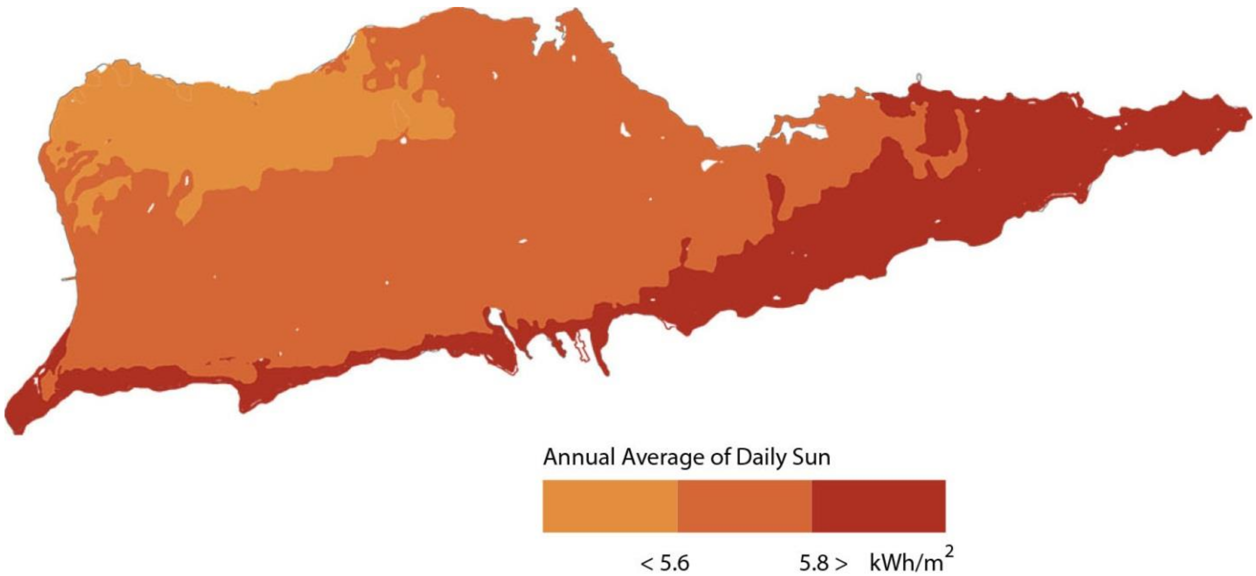

Figure 4: USVI Solar Resource Map [Abraham]

Using the Solar resources map as a guideline for ideal solar locations the figure below depicts the location of different scales of solar PV sites. These locations are primarily on government buildings however, are also utilized by residential houses and each person can contribute to the overall energy grid.

Figure 5: Optimal solar locations map [Abraham]

From a design stand point solar PV and SWH systems do not have an large impact on view sheds because majority of them will be situated atop building structures out of site. The 451 kW PV system at the Henry E. Rolsen Airport is an example of a typical large-scale PV system.

Figure 6: Installed solar panels at Henry Rolsen Airport, St. Croix [Abraham]

4.4 Conclusions

The limited resources of St. Croix make energy a challenging dilemma. However, they are poised to be able to demonstrate the benefits of installing large scale energy efficiency and renewable practices. Island communities have the potential to take the lead and become a showcase for how to transform largely oil dependent nations to ones of self-sufficiency.

Reducing oil consumption 60 percent by 2025 is ambitious and will only be accomplished through the use of efficient, renewable, green energy technology. The outcomes that work well within this process can be used for other island communities that face similar challenges in the energy crisis. Obtaining a sustainable energy future will only be achieved if existing initiatives and resources are identify and used to maximize their potential within the system.

Chapter 5: Design Proposal

5.1 Development of Form and Theme

The question of how to shift the perceived view of disaster recovery as a linear, static phenomenon to a dynamic decision making process of recovery will be further explored through design. The literature review pointed out that disaster management can be defined as a "collective term encompassing all aspects of planning for and responding to disasters, including both pre- and post-disaster activities"[60]. The precedent studies add an additional "real life" layer to this idea of creating a culture of prevention instead of reaction. The design phase of this paper aims to design in a way that is sustainable both from a structural and a cultural point of view.

The following guiding principles were created to capture the key emergency management goals and objectives that were used to shape specific public spaces on the island of St. Croix.

5.1.1 Emergency Preparedness Goals:

1. *Re-Invent the Emergency Management Plan*

Create a structurally sound emergency management plan that incorporates cultural ideologies with sustainable practices to better prepare St. Croix for threats related to hurricane damage.

2. *Put Sustainable Design at the Forefront of Redevelopment*

Reinvent the energy system to more efficiently use natural energy to power the island primarily through wind and solar technology.

3. *Reconnect the Island to its Waterfront*

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[60] (DISASTER MANAGEMENT An Introductory n.d.)

The waterfront should act as a front porch to the downtown neighborhoods and the multiple cities on St. Croix that border it. Building a network of protected spaces along the coastline, both in the water and on land, creates a more inviting space while serving as a barrier to the effects of hurricane destruction.

5. *Improve Access and Mobility*

The isolated nature of the island commands a need to have rations and shelters, and a systematic plan for dispersing these items in place immediately after a natural disaster strikes. A plan that identifies primary and secondary roads, buildings and energy sources will allow for a more focused recovery effort.

5.1.2 Cultural Management Goals:

1. *Embrace and Celebrate St. Croix's Past, Present and Future*

The island as a whole is a lens through which to understand the culture from its natural history and early Indian settlements, to the rich variety of maritime, industrial, commercial and recreational activities today.

2. *Create an island for all*

The island should engage the entire community. It should be a place for locals and visitors alike. A place where everything comes together and co-mingles effortlessly while serving a larger goal of protecting its inhabitants.

3. *Create a vision that is flexible over time*

The vision for the Island should clearly define how the process will take shape and how the essential character of key elements can easily be displayed. At the same time, the vision must be flexible to adapt to the changing cultural shifts.

5.2 Three Levels of Design

Due to the varying size of the design interventions, three scales were chose to focus on in the following sections: the island scale, the city scale and the waterfront scale. These three components each focused on current difficulties regarding water, power, road and building infrastructure, and then proposed design changes that improve the function to better serve the community after a hurricane.

5.2.1 Island

At the island scale, the focus is on long term sustainable design that is able to weave into the existing fabric and culture of the island. This design proposal follows the principles laid out in the "base case" energy efficiency plan, mentioned in Chapter 4, and utilizes emergency principles to identify shelters, roadways and buildings of highest importance. Four interventions were addressed on the island scale..

Issues:

1. Lack of Disaster Management Plan

- Individuals are not aware of overall mitigation plans and procedures.
- No clear identification of shelters or cleared roads.

2. Flooding

- There is a mixture of above and below ground runoff that floods particular areas and can become dangerous during periods of heavy rainfall.
- Piers and boardwalks were not built to withstand heavy amounts of storm surge and if destroyed, would cripple the island.

3. Outdated Energy Systems

- All power lines are above ground and are easily destroyed during hurricanes.
- Government buildings account for 36 percent of energy needs on the island.

- Current Water and Power Authority is opposed to new forms of sustainable energy and wants to just continually update the current system

- Install solar water power heaters in each house.

- Utilize the south shore of the island for solar and wind harvesting because of the expansive flat and protected land.

- Mandate that commercial/ government buildings be powered by solar energy.

4. Deconstruction of Hess Oil Refinery

- Unused land that is now a brownfield.

-No access to this land because of current ownership.

Proposals:

1. Lack of Disaster Management Plan

- Have marketing and ad campaigns that spread awareness.

- Create signage that guides people during such disasters.

2. Flooding

- Find key points of water runoff that overlap with key road systems and mitigate at the source.

- Increase the amount of permeable pavers to help with runoff.

- Construct jetties or manmade reefs aimed at mitigating storm surge.

3. Outdated Energy Systems

- Offer incentives to use and install new power options.

- Install energy harvesting techniques in public spaces for people to understand and learn about the methods.

- Identify ideal spaces where solar and wind can be harvested throughout the island.

4. Deconstruction of Hess Oil Refinery Site

- Clean and repurpose site.

- Utilize site to store supplies for disaster relief.

- Maintain port entry in case of disaster.

Design Ideas:

1. Lack of Disaster Management Plan

- Based on disaster management handbook, erect signage and early warning sound systems that can guide people to safety.

- Utilize TV, radio and newspapers to spread the word about evacuation routes, shelters and hospitals.

- Establish a hierarchy of roadways, buildings and energy sources that are of key importance prior to, during and after a hurricane.

2. Flooding

- Specify points of mitigation to address overland water flow.

- Address long term sewer issues with creative ideas to hold, re-use and re-distribute overland flow.

3. Outdated Energy Systems

- Install solar water power heaters in each house.

- Utilize the south shore of the island for solar and wind harvesting because of the expansive flat and protected land.

- Mandate that commercial/ government buildings be powered by solar energy.

4. Deconstruction of Hess Oil Refinery Site

- Repurpose oil containers to hold supplies such as building material, water and other necessities.

- Open port up to public to use in case of natural disaster.

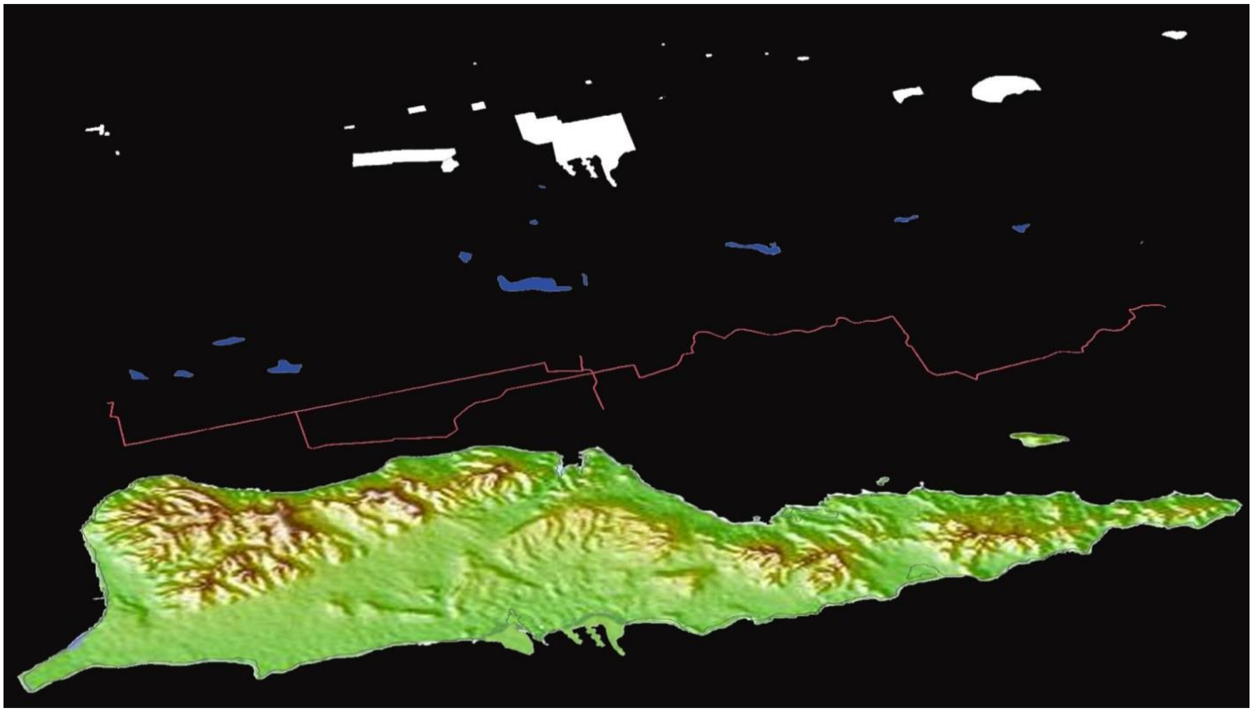

Figure 7: Overlay map of buildings, roads and flood prone areas on St. Croix [Abraham]

Flooding

The mountainous terrain and poor sewer systems on St. Croix give rise to areas of extreme flooding within the interior of the island. Hurricanes often produce widespread, torrential rains in excess of 6 inches, which may result in deadly and destructive floods. Flooding is one of the major threats for people living inland and severe flooding to critical facilities or roadways typically result in unfavorable consequences. Mitigation strategies include installing a basin under the roadways to hold some of the water while increasing the height of the road to minimize pooling water. The images below show a specific place on the island that frequently becomes inundated with water after even small rain showers. This spot was chosen because it is located on a major roadway and will need to be utilized immediately after a natural disaster. The two images on top show how the current design responds to a simple rainstorm with the before and after effect shown. While the two images on the bottom depict the same rainfall amount, they are utilizing the design techniques laid out in this thesis to help mitigate flooding.

Outdated Energy Systems

The current electrical distribution configuration is susceptible to damage by both wind and water damage. Their proximity to coastal areas that are susceptible to flooding coupled with their outdated infrastructure reinforces the urgency for new techniques and process to be introduced to the Virgin Islands. The image below depicts locations where a wind farm would be most suitable as well as a perspective of land area the wind turbines would cover.

The "footprint" of the turbine can typically be averaged around 0.25 acres per machine, however, that number does not include the diameters of space needed between turbines to avoid collisions. To account for necessary room between the turbines the boundary perimeter is typically around 1-2 acres from base to base of all machines. It is important to understand that all space between the turbines can still be obtained for its

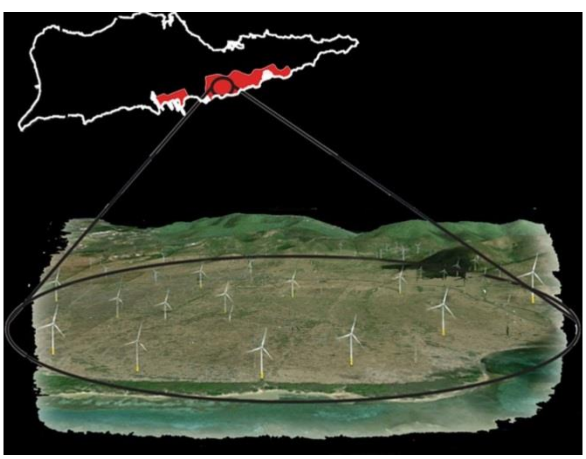

Figure 8: Areas of wind turbine generation [Abraham]

original purpose of wildlife habitat, farming, or in the aftermath of a disaster, for moveable shelters.

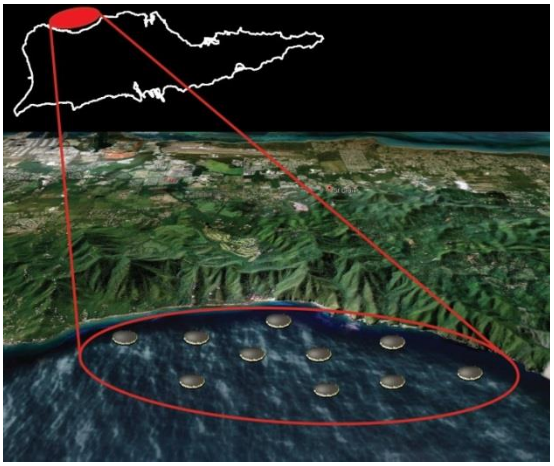

Figure 9: Area of solar power generation [Abraham]

[61] The other option for energy collection is by solar pannels. The private and commercial buildings can both install solar panels of different sizes and to accomplish different purposes. One of the main drawbacks of solar energy is that they require large areas of land for solar farms. As noted in previous chapters, there are not many locations where solar would be a suitable option at that scale, however new technology has created alternatives to consider. The image to the left depicts a floating solar farm that can be anchored to maintain its general position, but moves with the tides to prevent heavy storm surge damage. In the event of a hurricane, the "solar islands" can be brought to a more protected location and then put back in place once the storm subsides to provide additional energy needs.

Deconstruction of Hess Oil Refinery Site

Hess oil refinery was often called "the city" by locals because of the sheer size and the presence it commanded on the island. After its close in 2012, all that is left is abandoned buildings. The site is now a brown field and is unusable unless it is

[61] (Maps 2013)[61]

completely cleaned up. However, this is the site of the second deepest port on the island of St. Croix, and can be utilized in the event of an emergency to get aid into the island. Because the island is so secluded, a port of any type is of high demand after a natural disaster for the import of food, clean water, supplies, and in some cases, evacuation. The four images below show the current use before and after a disaster as well as the proposed design implementation before and after, that show this port in service.

Figure 10: View of Hess Oil Refinery current conditions [Abraham]

Figure 11: View of Hess Oil Refinery current conditions after a hurricane [Abraham]

Figure 12: View of Hess Oil Refinery proposed changes [Abraham]

Figure 13: View of Hess Oil Refinery proposed changes after a hurricane [Abraham]

5.2.2 City

Initial identification of key building and road infrastructure helped guide the emergency management plan to be able to point out the best location for shelters, hospitals, emergency rations and entry points for rescue teams. Majority of Christiansted will undergo changes outlined in the 60x25 plan such as storm water drainage improvements, solar roofs and improved function and flow of the town as a whole. These elements come together to create a dynamic city that is completely self-sufficient with plans in place to be prepared for almost any disaster that strikes.

Figure 4: Ariel view of Christiansted [Abraham]

Christiansted is located on the northern portion of the island and is fairly closed off from the rest of the island both visually and through access ways. There is one major road that runs through the town and very few areas of open gathering space as most infrastructure was built in the 1700's without major updates since that time period.

Figure 15: Map of Christiansted grid pattern [Abraham]

This grid pattern of streets is how people moved within the city limits. Starting with the most extreme case of complete isolation, several key components were identified and assigned hierarchies on a scale of one to three (one being the most imperative for survival, and three being the least imperative).   Moving from the city limits inward, the key roadways, buildings of importance and tracts of usable open space were identified and labeled with the hierarchy ranking.

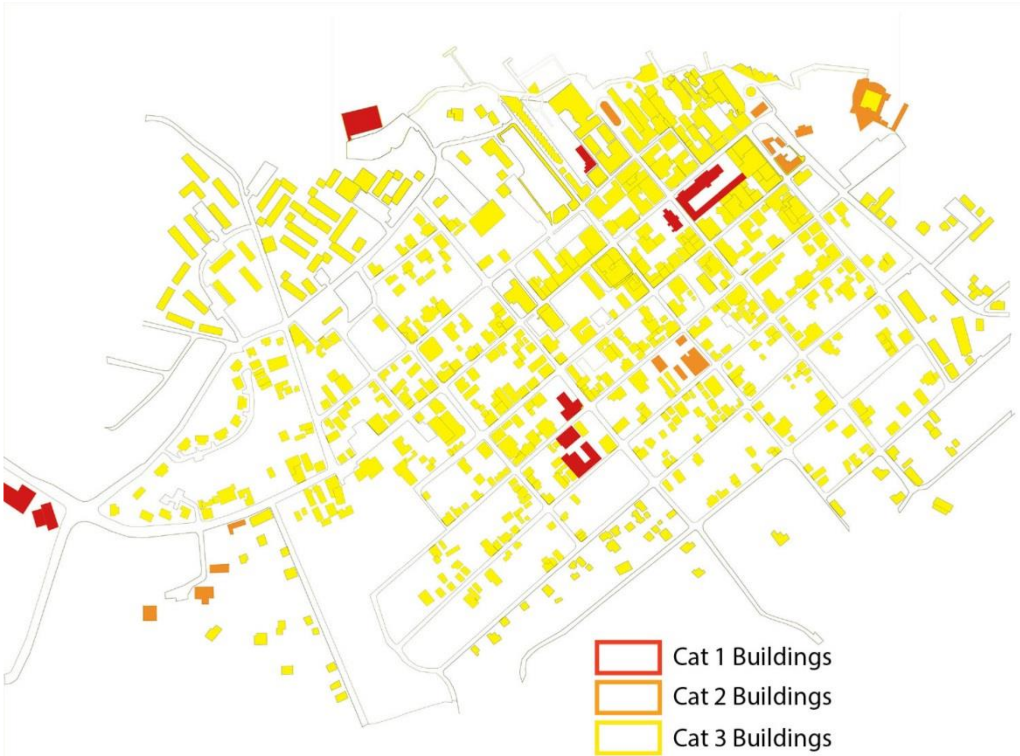

Figure 16: Map of building categories [Abraham]

Figure 17: Map of three levels of roads [Abraham]

The roadways hierarchy map was assigned values based on the quality of the road. This quality assessment was reached by measuring width, cars per day, connections to other major roadways and surrounding infrastructure. The building hierarchy map was assigned based on historic relevance, the vital importance to maintaining order within the city, and size. While 58 percent of the buildings within the town are not priority one or two, they will still undergo protection efforts and re-location opportunities if there is a complete failure of the structure.

Based on the roadway and building ranking maps, a system of emergency centers were located in key places throughout the city. Utilizing both civic and private land opportunities, several locations for shelters, hospitals and vital resource entry points were identified and the design proposes changes for more efficiently.

Figure 5: Map of key buildings and drop off areas [Abraham]

Energy

The secluded nature of this city makes small power outages seem like catastrophic events. Measures are currently underway to bury all overhead electrical lines that will improve views as well as reduce the risk of storm damage by wind or flying debris. However, the reliance on all gas powered energy is not sustainable and becomes a huge issue in the event of a natural disaster. This design proposes weaves alternative forms of energy into the residential and commercial landscape through things such as solar roofs and solar water heaters on both residential and commercial buildings. With nearly 3,000 people living in this city, having access clean water and electricity is crucial to mitigate the spread of disease and famine after a disaster.

Sewer

Similar to the buildings in this city, the sewer and drainage systems were installed in the late 1800's and have not been updated since. The majority of the sewage and water systems are concrete, which can be subject to deterioration from hydrogen sulfide gas if large amounts of raw sewage travel slowly through the pipes. Because the task of replacing the sewage pipes was so monumental, this design focused on the overland flow of water into storm drains and water catchment areas.

As mentioned, the majority of the storm water pipes are made of concrete and are a mix of above and below ground piping. The lack of plant material along the roadside has increased the water runoff rate and caused the streets to become inundated with small streams. The Christiansted harbor has higher than average sediment and chemical infiltration levels. To counteract this effect, bio swales and planting beds will be added to several streets and alleyways at major water runoff points.

Figure 19: Locations of bioswales within city limits [Abraham]

Figure 20: Section of King St. with a bio-swale [Abraham]

Figure 21: Perspective of bioswale looking north towards Christiansted harbor [Abraham]

Limited open space for shelter/supply drop off

The current grid layout of Christiansted as well as the shallow port entry does not allow for many potential locations for mass shelters or aid/supply drop off points. However, several key points have been established in the event of total isolation from the rest of the island. Several alternative modes of supply pick up and drop off were explored to see which ones fit within the grid in the most appropriate locations. The diagram below depicts these various modes and their location within the context of the city.

Figure 22: Diagram of emergency areas [Abraham]

The above disaster relief areas have been chosen because of their vicinity to the specific issues they are tasked with mitigating.

5.2.3 Waterfront

The waterfront improvements implemented in the city of Christiansted intends to set a new standard for innovative and functional spaces that mitigate the damaging effects of a hurricane on a coastal community. Six character zones distinguish themselves along the waterfront and were influential in helping to narrow specific design implementation. One primary design proposal is a continuous public boardwalk that is built defensively to provide protection from storm surge, debris and wind.

Segment	Approximate Linear ft. along water
A- Overlook	320
B- Open Park Space	480
C- Picnic / Seating Area	240
D- Re-Developed	170
E- Commercial Zone	750
F- Private Land	400
Total:	2360

Figure 23: Boardwalk sections [Abraham]

These zones are defined by physical characteristics of the site, such as topography and urban form, as well as the structurally protective qualities they embody. A project of this magnitude required the understanding of many aspects to fully understand the interrelated goals needed to improve this space.

Goals:

1. Address the importance of planning for sea level rise and the increased risks from storm surges.

2. Recognizes the importance of innovative disaster design and highlight Christiansted, St. Croix as an example of design innovation that should become more standard over time.

3. Create waterfront infrastructure improvements such as Community Eco-Docks that will better withstand hurricane force wind and water.

4. Realizes the importance of building open space and waterfront access with a the outcome of not just allowing access for people, but also providing emergency shelters and aid.

The central boardwalk area extends nearly a mile along the shore of the Christiansted harbor from the sea plane landing area to the historic Christiansvaern Fort. The stretch of public waterfront is a unique and quintessential part of the city representing its culture and economic, and can serve as protection from natural disasters.

The design proposal:

Issues:

1. Storm Surge

- Increased overland flow of water

- No shield for the buildings from wind or water damage

- Failing bulkhead installed along the waterfront of the fort

- Loss of reef has caused lower fish diversification in the Christiansted harbor.

- Lack of barriers has allowed debris to wash ashore during storms

2. Outdated sewer system

- Sewers were built in the 1800's and are beginning to fail.

- There is a mixture of above and below ground runoff that needs to be addressed.

- Streets are being built higher than the building base levels so water sometimes doesn't make it to the sewer and goes directly into the building.

3. Limited open space for shelter/supply drop off

- No formal gathering space designated

- No areas large enough to accommodate big crowds

- Town is segmented between commercial and residential sectors

- Most open space is along the waterfront is where tides are likely to be high after storm

4. Lack of renewable energy

- Commercial buildings account for 56 percent of power usage in Christiansted

- During natural disasters power is the first thing to be interrupted and it often takes weeks to be restored because of overhead power line damage

Solutions:

1. Storm Surge

- Incorporate plants into landscape more effectively

- Replace bulkhead/boardwalk with soft shoreline

- Create fish and bird habitat

- Build a manmade reef

- Incorporate barriers into the area that are functional and provide protection

2. Outdated sewer system

- Find key points of water runoff and mitigate at the source

- Increase the amount of permeable pavers to help with runoff

- Lower street levels

3. Limited open space for shelter/supply drop off

- Enhance one central location to make it a space for all

- Pre-plan for specific community events and have design layout options for review and comment to determine what type of space is needed and can accommodate a specific number of patrons

- Increase the connectivity between residential and commercial areas through street trees, view sheds and similar patterns throughout

- Designate space for supplies received by boat, helicopter and automobile

4. Lack of renewable energy

- Install energy harvesting techniques in public spaces for people to understand and learn about the methods

- Utilize the solar and wind that can be collected throughout the site

- Enforce a net zero balance on all buildings

Design Ideas:

1. Storm Surge

- Create spaces that are shaded by trees to provide a more enjoyable experience as well as protect buildings from wind, such as bus stops or recycling drop-off points

- Construct floating wetlands to provide a protected area for animals to live

- Create manmade reefs to act as a wave barrier and provide habitat for marine life

- Install low seat walls at key points along boardwalk to minimize storm surge impact

2. Outdated sewer system

- Shave down street levels and replace main streets with permeable pavers or heavily plant the exterior

- Specify two points of mitigation to address overland water flow

- Address long term sewer issues with a master plan

- Deal with water run-off along the streets by creating planting beds in current gutters that run along streets

3. Limited open space for shelter/supply drop off

- Reconstruct 3 spaces totaling in 30,000 square feet to become points for supply and to aid distribution

- Create a hierarchy of roads to know what to clear first in order to create movement through the city

- Designate the Fort lawn, NW parking lot and SW church lawn as aid and relief stations

4. Lack of renewable energy

- Install solar voltaics to power water heaters in each house

- Create a public installation that teaches people about the uses and process of energy harvesting

- Mandate that commercial/ government buildings be powered by solar energy

Figure 24: Plan of Christiansted Wharf area [Abraham]

Storm Surge

The Christiansted harbor design was influenced by the idea of a landscape at the front lines of defense that could absorb the impact of a hurricane. This stretch of waterfront was conceived as a land of absorption that takes water, wind and debris from every direction. This concept led to a rethinking of the material textures from the bottom of the ocean to the city streets. Transformed through new wetlands and coral reefs, the coastal area is a natural instrument for filtering both tidal changes and runoff after storms. Some of the streets have been "greened" through re-surfacing in absorptive, open-mesh concrete tiles and a layered filtering system.

A man made coral reef that stretches 1.3 miles is the start of the protection measures against storm surge in the harbor.   This reef is created in shallow coastal waters to attenuate waves, particularly during storm surges. The reefs create a new recreational opportunity, without diminishing the vista of the Caribbean ocean that can be seen from the Christiansted boardwalk.

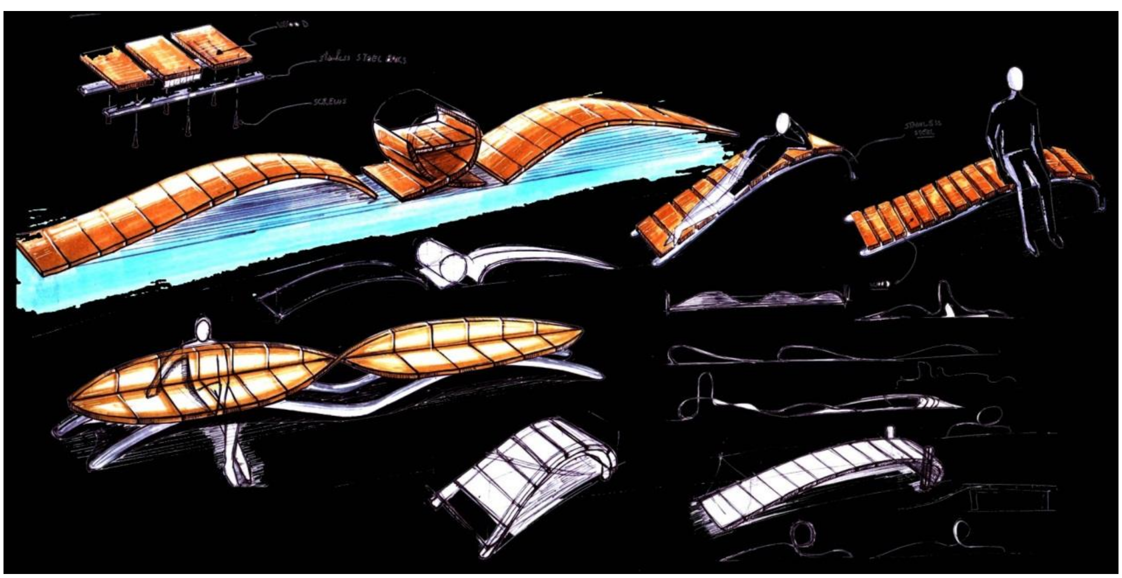

Figure 25: Sketches of wave benches [Abraham]

The second line of defense is the several wetland areas located at key points along the boardwalk that mitigate additional storm surge energy and help reduce debris overflow into the city. A boardwalk and wetland partnership is the gate to the city. On the boardwalk, the wave-attenuating piers freely move with the tides and the boats docked to them are less likely to suffer extreme damage because of this flexibility. Boardwalk structures are fabricated from engineered lumber composite decking boards that are easily replaced if they come loose. The composite material allows the boardwalk to last longer without maintenance in the extreme Caribbean climate with intense sun, salt water and hurricane storm surge sized waves. A principle of this research is that a softer shoreline will create a more resilient edge, which is better able to connect both increased storm surge flooding and sea level rise. The projected rate of sea level rise is 1.98 mm per year,[62] so while the larger implications of this are being examined, the larger issue focuses on periodic storm surges.

The last line of defense from the threat of storm surges is the implementation of wave seats that act as a physical barrier for large debris and swollen waves that may reach shore. Their whimsical look and feel allows them to blend into the Christiansted waterfront area without diminishing the connection between the land and the sea from the human point of view.

62

Figure 26: Section of emergency shelter area at wharf [Abraham]

With three lines of defense, the infrastructure closest to the waterfront is projected to have a more favorable survival rate from a natural disaster of similar magnitude. Perspectives one and two below depict the before and after effects of a storm on an area directly abutting the waterfront that is currently a gravel parking lot with a small strip of boardwalk as its boundary to the ocean. The following two perspectives have utilized several new design ideas that have increased the resiliency of the area after a storm. The jumping pier/play area along the boardwalk acts as a wave break, and the addition of a reinforced berm and depression help mitigate water flow onto the site. Farther into the area, there are a series of telephone post that seem to be sculptural art on most days, and then transform into tent post to house residents in shelters that are strung from post to post creating private rooms within this civic area.

Figure 27: Perspective of current boardwalk design [Abraham]

Figure 28: Perspective of current boardwalk design after a hurricane [Abraham]

Figure 29: Perspective of proposed boardwalk design [Abraham]

Figure 30: Perspective of proposed boardwalk design after a hurricane [Abraham]

Outdated sewer system

As previously mentioned, the city's outdated sewer system is one of the main issues in Christiansted. The system must successfully transport water to the desalination plant. After a storm, many of the gutters become clogged with sediment or debris, and the drainage failure contributes to much of the overland water flow in the city. One portion in particular towards the west end of the boardwalk has water gather from both the ocean and the runoff of the streets creating a stagnant water situation. This particular spot becomes inundated with water that then produces a very pungent smell. The following images show this portion of the boardwalk in its current design before and after a storm as well as with the alternative design proposed implementation before and after a natural disaster. By creating a soft shoreline this area is able to utilize the tidal flush to expel still water and to absorb additional water through the use of a vegetative planting. In other areas of the city the old system of above-ground concrete sewer systems is replaced with bioswales that are able to filter the water before it reaches the ocean.

Figure 6: Stormwater system outfall area current design [Abraham]

Figure 7: Stormwater system outfall area current design after a hurricane [Abraham]

Figure 33: Stormwater system outfall area proposed design [Abraham]

Figure 34: Stormwater system outfall area proposed design after a hurricane [Abraham]

Limited open space for shelter/supply drop off

The lack of contiguous open space provides little gathering space for areas of shelter and aid. The largest piece of land is owned by the National Parks Service, formerly the Christansavern Fort. The open lawn to the southwest of the fort can be utilized as a helicopter landing area next to one of the main aid stations. This location is central to both the city of Christiansted as well as the adjacent communities. The perspective below shows the lawn with its current design before and after a natural disaster as well as with the newly designed programing before and after a disaster.

Figure 34: Fort open lawn current design [Abraham]

Figure 36: Fort open lawn current design after a hurricane [Abraham]

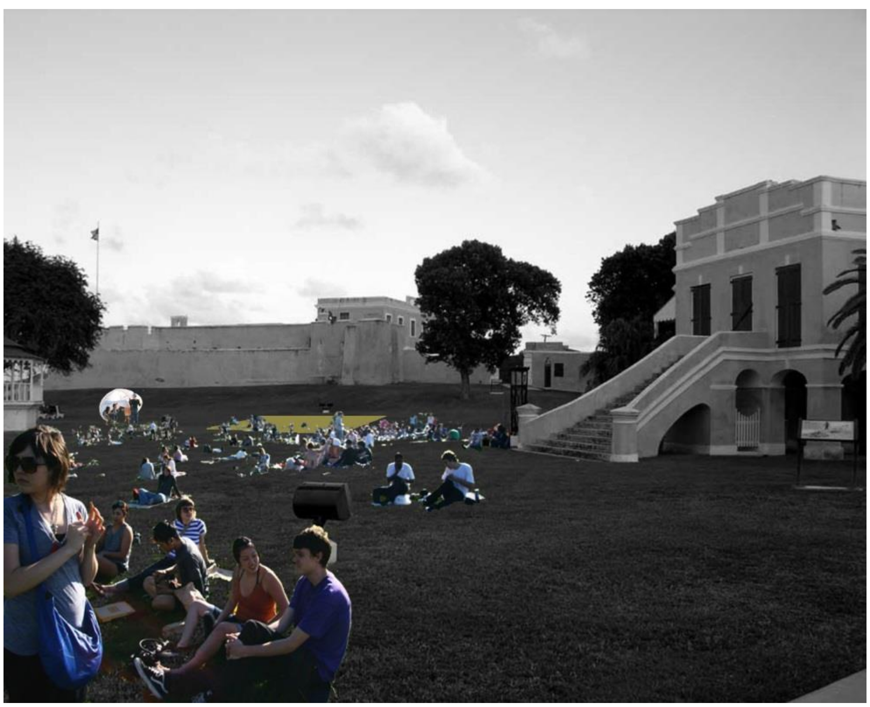

Figure 37: Fort open lawn proposed design [Abraham]

Figure 38: Fort open lawn proposed design after a hurricane [Abraham]

Aside from a 20x20 square foot area of compacted earth utilized as a helicopter pad, there are no significant changes proposed for the site. The largest impact will be temporary re-purposing of the area in response to the need for aid. The site is broken into zones that accommodate sections for food distribution, housing units, and medical emergencies facilities.

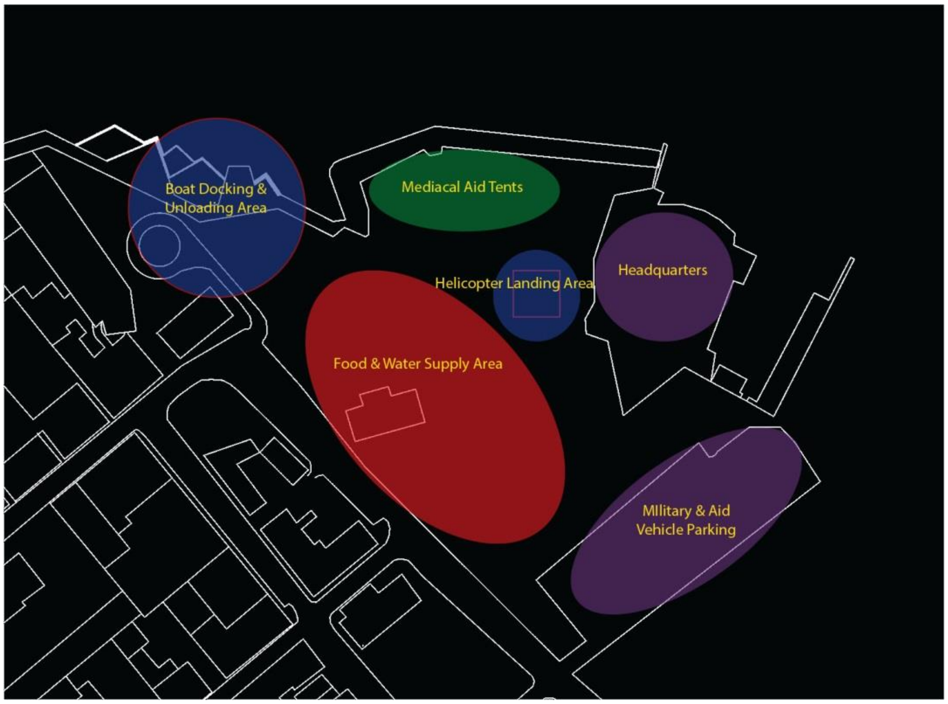

Figure 39: Diagram of Fort open lawn after a hurricane [Abraham]

Lack of renewable energy

While the boardwalk requires little energy consumption because it is designed to be completely self-sufficient. Solar powered lighting at its edge and a demonstration "solar tree" that is compiled of small solar panels as leaves stands at the center of the taxi pick up and drop off round-a-bout. The design creates an atmosphere based on the idea of renewable energy. On the regulatory level, each house and commercial building will be given incentives to update their current energy usage including some form of solar or wind energy.

Chapter 6: Summary and Conclusions

The island of St. Croix is familiar with the trials and tribulations of a hurricane. Hundreds of years have passed with the same outcome of a strong community that can withstand disasters, and rebuild. However, the shift from a culture of reaction to a culture of prevention is necessary in order to survive new and increasing destructive weather patterns.

Responding to this lack of preparedness, this design-research thesis suggests implementing specific emergency management practices and design guidelines that will simplify the chaotic times after a natural disaster.   This thesis identifies key hazards, major vulnerabilities, and historical disaster events by providing a detailed look at the emergency management history in the USVI. Combined with vulnerabilities such as having limited natural resources, being an isolated island it becomes evident that there must be an ongoing look at the changing future of this island the their emergency management protocols.

Through the exploration of three levels of design, this thesis displays techniques for the Virgin Islands to become the standard for other Caribbean islands. The territory can become a showcase to other small-island nations demonstrating what can be accomplished when a thorough emergency management initiative is implemented.

The response of a community, both from man-made and natural events, is fundamentally based on the responses of its citizens. An interdisciplinary approach to the field of disaster management that views landscape architecture as a central element—rather than second—will lead to stronger, more resilient communities, and result in better decisions on the part of government, hopefully reduce the need for extreme measures of damage control in future catastrophes.

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