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CLOSING THE GAP:
TINY HOMES, SOCIAL CAPITAL, IMPLEMENTATION, AND DISASTER RECOVERY

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CDC – Centers for Disease Control and Prevention

CH_2O - formaldehyde

CO_2 – carbon dioxide

ESF – Emergency Support Function

GAO – Government Accountability Office

HUD – Department of Housing and Urban Development

IDP - Integrated Design Process

IPD – Integrated Project Delivery

FEMA – Federal Emergency Management Agency

LCA – life cycle analysis

LEED – Leaders in Energy and Environmental Design

MHU – manufactured housing unit

NDRF - National Disaster Recovery Framework

NRF – National Response Framework

NRP – National Response Plan

NZGW - net-zero greywater

MIR – Make It Right

PV – photovoltaic

RV – recreational vehicle

RWH – rainwater harvesting

US – United States

US$ – United States Dollar

Abstract

Over the last fifteen years, the United States has experienced an exceedingly high number of devastating hurricanes; these storms have affected the nation in ways that are still being examined and dealt with years after the last raindrop. The Federal Emergency Management Agency has responded to these catastrophes in many ways. The focus of this research is the handling of disaster relief housing by the United States government and how the decisions made have impacted the environment, society, and the economy. After a thorough analysis of the impacts of decisions made in the aftermath of some of the costliest hurricanes in American history, a more sustainable alternative is presented for the implementation of housing in the form of off-grid tiny homes, supporting a sanguine future for storm victims.

Keywords: disaster relief housing, hurricane recovery, off-grid housing, resilience, social capital, sustainability, tiny homes

CHAPTER 1: INTRODUCTION

This research looks at the impacts of the decisions made by the Federal Emergency Management Agency (FEMA) after Hurricane Katrina for housing people displaced after the storm and compares them to the decisions made over a decade later following Hurricane Harvey to determine what has been done to improve the process and what areas have continued to be ignored. The significance of this study is to gain a thorough understanding of the needs yet to be addressed and to provide sustainable answers to housing and recovery problems regularly faced in post-hurricane disaster planning.

The questions presented in this research are

- Is there a more sustainable solution for disaster relief housing than the trailers that have been used in the past?
- What can be done to implement the solution found?

To address the core concepts of sustainability, which include economy, environment, and society, the scope focuses on the expense in US dollars (US$) regarding emergency relief housing, impact on the environment due to water consumption and carbon dioxide (CO_2) emissions from energy use, and human health concerns raised in respect to formaldehyde exposure and mental stress.

The topics discussed are

- tiny houses and their use throughout history as adaptable, affordable homes, and how these dwellings can be used as effective relief housing;

- design techniques as a means of reducing environmental impact through energy efficiency and improving human health with better indoor air quality by utilizing proper ventilation and flow;
- the mental and physical health benefits of building social capital and the role of social capital in coordinating relief efforts.

1.1 Background

Hurricane Katrina

The storm. Hurricane Katrina was a week-long event that started on August 23, 2005, in The Bahamas, making its way through the southern tip of Florida and circling down into the Gulf of Mexico before heading north through the American Bible Belt. The storm affected several Gulf countries, including at least three states in the United States (US) – the hardest hit being Louisiana, particularly the city of New Orleans on August 29.[1] According to the National Hurricane Center, a division of the National Oceanic and Atmospheric Administration, approximately 80% of the city of New Orleans was flooded in waters up to 20 feet (6.10 meters) deep due to storm surges that stressed and breached the levee system.[2]

The damage was significant, the total loss amounted to US$125 billion (not adjusted for inflation), making it the costliest hurricane to hit the United

[1] National Oceanic and Atmospheric Administration, "Historical Hurricane Tracks," accessed October 3, 2018, https://coast.noaa.gov/hurricanes/.
[2] Richard D Knabb, Jamie R Rhome, and Daniel P Brown, "Tropical Cyclone Report Hurricane Katrina 23-30 August 2005," 2005, https://www.nhc.noaa.gov/data/tcr/AL122005_Katrina.pdf.

States since 1900.[3] Due to widespread flooding, many people lost their homes, whether permanently or temporarily, and local governments had to seek federal assistance to house those displaced by the storm. President George W. Bush declared a state of emergency, enacting the Stafford Act[4] and triggering a response from FEMA.

Pre-Katrina, FEMA was utilizing the Federal Response Plan, a framework that had been in place since 1992, with its most recent changes implemented in 2003. In the Federal Response Plan, the Red Cross was the sole entity responsible for mass-care and relief housing.[5] After Katrina, FEMA was operating under the National Response Plan (NRP) of 2004[6] under which relief housing was part of the Emergency Support Function (ESF) #6 and deemed FEMA and the American National Red Cross duly responsible for coordinating action. Thus, the NRP, being a year old and untested as an action plan, especially on a Katrina-level scale, was FEMA's first exposure to coordinating this effort.

ESF #6 contained short- and long-term housing assistance, including rentals, temporary housing, loans, and replacement of primary residences; it also involved human services that focused on assisting individuals with special needs, dealing with emotional trauma, and providing other supportive post-

[3] National Hurricane Center, "Costliest US Tropical Cyclones," 2018, https://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf.
[4] The Stafford Act is a law which prompts federal assistance after the damage from a natural disaster overpowers local government's ability to manage.
[5] Francis X Mccarthy, "FEMA Disaster Housing and Hurricane Katrina: Overview, Analysis, and Congressional Issues Analyst, Emergency Management Policy Government and Finance Division," 2008, https://www.everycrsreport.com/files/20080626_RL34087_3589fbe2b9ef4969781a461cca14b34b36e208b3.pdf.
[6] US Department of Homeland Security, "National Response Plan," 2004.

disaster services. ESF #14 included long-term community recovery to ensure restoration of permanent housing, infrastructure, and the local economy. This section also involved mitigation planning by assessing areas post-disaster to measure the effectiveness of previous recovery strategies. Despite this framework, the country was not prepared or equipped to handle the ravaging destruction brought about by Hurricane Katrina.

What went wrong. In February 2006, at the request of President Bush, a team directed by Frances Townsend, Assistant to the President for Homeland Security and Counterterrorism, conducted a full report detailing the storm's path and havoc, the federal response to the disaster, what went wrong with the plan that was in place, and most importantly, what was learned. The 228-page report Townsend provided, titled "The Federal Response to Hurricane Katrina: Lessons Learned,"[7] included a list of recommendations following each lesson, setting the stage for a more robust framework to be established. The report takes the opportunity to address the fact that FEMA is a small organization meant to coordinate and manage communication between federal agencies. However, the scale of Katrina's devastation overwhelmed the appropriate entities meant to handle relief housing; due to this, the agency was no longer acting in its role of coordinator forcing it into direct involvement with meeting the housing needs of victims. At that point, FEMA was operating outside of

[7] Frances Fragos Townsend, "The Federal Response to Hurricane Katrina: Lessons Learned," 2006, http://www.au.af.mil/au/awc/awcgate/whitehouse/katrina/katrina-lessons-learned.pdf.

standard procedure, having to make daily, critical decisions with little experience or information.[8]

As is evident by the literature reviewed, a lack of communication and planning led to many situations in which FEMA was unable to accept assistance from a variety of sources including domestic and international governments, non-profit organizations, and other federal agencies; because of this, many housing units and resources were left unused, though desperately needed.[9] Many residents of New Orleans who were willing and able to evacuate found shelter in other states; however, those who were unable due to disability, ill health, age, or income restrictions were forced to seek refuge in the hotels, apartments, and condominiums in and around affected areas. The demand for shelter overwhelmed local accommodations leading to the necessity of temporary housing units for victims.

Qualification for assistance was loosely determined upon applications and inspections. It was found that FEMA staff was not trained to review the applications properly to ensure valid social security and address data was used. This led to approximately US$1 billion in improper and fraudulent housing assistance payments made.[10] This mishandling of funds is one more

[8] US Department of Homeland Security, "National Disaster Housing Strategy," 2009, https://www.fema.gov/media-library-data/20130726-1819-25045-9288/ndhs_core.pdf.
[9] Townsend, "The Federal Response to Hurricane Katrina: Lessons Learned."
[10] US Government Accountability Office, "Hurricanes Katrina and Rita: Unprecedented Challenges Exposed the Individuals and Households Program to Fraud and Abuse; Actions Needed to Reduce Such Problems in Future," 2006, 4, www.gao.gov/cgi-bin/getrpt?GAO-06-1013.

piece of evidence of a lack of planning and miscommunication within government agencies.

A toxic environment. In the event of a disaster, the Stafford Act would normally require FEMA to first seek local contractors in the areas involved, however, uncertainty of the scale and devastation of the storm led the agency to seek assistance outside of the states affected. Some of the main contractors hired by FEMA were Gulf Stream Coach, Inc., Shaw Group, Inc., Bechtel National, Inc., Fluor Enterprises, Inc., and CH2M Hill Constructors, Inc. These companies were some of those contracted to design, manufacture, install, and inspect the trailers provided to victims of Hurricane Katrina. Tessa Anderson, who was involved in Strategic Communications of CH2M Hill, acknowledged in an article she wrote, that under the FEMA contract, the company was responsible for assessing sites and the installation and maintenance of temporary housing units. She also states that CH2M Hill engineers and architects designed the units and that the company was to conduct monthly preventative maintenance inspections.[11] Despite Anderson's article, a survey conducted by the US Government Accountability Office (GAO) found that many of the contractors claimed to be unsure of their responsibilities due to miscommunication from government coordinators.[12]

[11] Tessa Anderson, "So What Exactly Does It Take To Install A FEMA Trailer?" (CH2MHill, 2006), https://www.jumpjet.info/Emergency-Preparedness/Neighborly-Response/Outside/So_What_Exactly_Does_It_Take_To_Install_A_FEMA_Trailer.pdf.

[12] US Government Accountability Office, "Agency Management of Contractors Responding to Hurricanes Katrina and Rita," 2006, http://www.gao.gov.

FEMA traditionally contracted and issued manufactured housing units (MHU) as long-term temporary housing, while using trailers[13] as a short-term solution allowing victims to be quartered in floodplains near their damaged properties. Dissimilar to MHUs, trailers are classified as transportation and because of this, the Department of Housing and Urban Development (HUD) had no established standards for long-term viability as housing. This lack of standards led to rising health concerns for victims who were using the vehicles as long-term living solutions and quickly became a topic of discussion across news outlets, leaving a lasting imprint on American history.

A rise in reports of illness from the victims of Katrina started pouring in by early 2006, mostly from upper respiratory symptoms such as sore throat, itching and burning in the nose and eyes, and nasal congestion. While it was not known for certain at the time, an explanation that physicians were suggesting was formaldehyde exposure.[14] Formaldehyde (CH_2O) is a colorless gas that can cause upper respiratory symptoms in people who are exposed to high concentrations for extended amounts of time. In 1987, the US Centers for Disease Control and Prevention (CDC) classified the compound as a probable human carcinogen, though it took until 2011 for the National Toxicology

[13] The word 'trailer' in this research includes mobile homes such as travel trailers and park models built on chassis and do not usually exceed 400 square feet (37 square meters).

[14] M. W. Murphy et al., "Formaldehyde Levels in FEMA-Supplied Travel Trailers, Park Models, and Mobile Homes in Louisiana and Mississippi," *Indoor Air* 23, no. 2 (April 1, 2013): 134–41, https://doi.org/10.1111/j.1600-0668.2012.00800.x.

Program, as part of the Department of Health and Human Services, to officially pronounced it a known human carcinogen.[15]

Media outlets began learning of the toxic levels of formaldehyde in FEMA trailers provided to victims after Katrina, broadcasting this information throughout the world. As a result of the illness victims reported and the attention the issue was receiving on a global scale, investigations and major lawsuits came about – creating another level of expense to post-Katrina recovery. In 2012, US District Judge Kurt Engelhardt approved a settlement of US$42.6 million to be paid to victims by the trailer manufacturers, as well as an additional US$5.1 million settlement paid by contractors used for installation and maintenance.[16]

The Lower Ninth Ward. Nature cannot discriminate, but in the case of Katrina, many people find that fact hard to believe. Areas like the Lower Ninth Ward in Orleans Parish were already fighting poverty, though people were getting by. The neighborhood has a vibrant and important place in US history as one shaped by free people of color who played a significant role in the civil rights movement, helping freed slaves find their way and start creating their own American dream.[17] Across the city of New Orleans, it was the neighborhood Katrina hit the hardest, a location that quickly became a major

[15] National Cancer Institute, "Formaldehyde and Cancer Risk - National Cancer Institute," 2011, https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/formaldehyde/formaldehyde-fact-sheet#r1.
[16] Matt O'Donnell, "FEMA Trailer Formaldehyde Class Action Settlement," Top Class Actions, 2012, https://topclassactions.com/lawsuit-settlements/lawsuit-news/2558-fema-trailer-formaldehyde-class-action-settlement/.
[17] L9W Homeownership Association, "Our Community" (Lower 9th Ward Homeownership Association, 2016), https://www.l9wha.org/about.

focus of media attention due to catastrophic flooding and obvious post-disaster neglect in comparison to more affluent areas of the city. Low-income neighborhoods often suffer environmental injustices due to cheap, unsafe land being all that residents can afford; the Lower Ninth is one of those neighborhoods, located in a floodplain where it is most vulnerable to hurricane season.

A Congressional Research Service report prepared for Congress on the topic of social-demographic characteristics of impacted areas provides data showing the Black population of New Orleans to have been disproportionately affected by Hurricane Katrina. It is estimated that 44% of storm victims were Black; in Orleans Parish alone, Black people accounted for 73% of the affected population.[18] Based on census data, of those who were likely to have been displaced by the storm, an estimated 34% were living below the poverty line.[19] The 2000 US Census reported 30.65% of Lower Ninth Ward residents were under the age of 18 and 14.01% were over the age of 65.[20] The median household income for the Lower Ninth according to the census of the same year was approximately US$19,918.20.[21] Total population for the area sat at

[18] Thomas Gabe et al., "CRS Report for Congress Hurricane Katrina : Social-Demographic Characteristics of Impacted Areas," 2005, 16.
[19] Gabe et al., 17.
[20] U.S. Census Bureau, "Census 2000 Age Groups and Sex: Summary File 1, Tract 7.01/9.01/9.02/9.03/9.04," accessed March 29, 2019, https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=DEC_00_SF1_QTP1&prodType=table.
[21] U.S. Census Bureau, "Census 2000 Economic Characteristics: Summary File 3, Tract 7.01/9.01/9.02/9.03/9.04," *Generated by Jenny Hamel Using American Fact Finder*, accessed February 3, 2019, http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_11_5YR_B03003&prodType=table.

14,008.[22] The Social Vulnerability Index map provided by the CDC for the year 2000 shows the five census tracts of the Lower Ninth Ward to have had an overall score of approximately 0.8724,[23] [24] indicating that the neighborhood had a low level of resilience when faced with external stressors, such as a hurricane.

For houses sitting in flood plains, as are many of those in New Orleans, most mortgage lenders require the asset to be covered by flood insurance due to the significant investment made on behalf of the borrower;[25] however, when residents own their homes outright, they are relieved of this obligation but also of the protection that insurance offers. The Lower Ninth was a locality with one of the highest rates of Black homeownership in the state of Louisiana, a statistic that would normally garner a much more positive outlook for the future of the area, but despite the implications that homeownership usually carries, many of the houses were passed down through generations and several residents were unemployed or struggling to pay their bills.

Regardless of difficulties many residents faced prior to Hurricane Katrina, especially in neighborhoods heavily affected by poverty such as the Lower Ninth Ward, neighbors were close, and the area thrived in its togetherness; it was a place in which people raised their families and where

[22] U.S. Census Bureau, "Census 2000 Age Groups and Sex: Summary File 1, Tract 7.01/9.01/9.02/9.03/9.04."
[23] Centers for Disease Control, "Social Vulnerability Index" (Agency for Toxic Substances and Disease Registry, n.d.).
[24] Possible scores on the Social Vulnerability Index range from 0 (lowest vulnerability) to 1 (highest vulnerability).
[25] "Getting a Mortgage for a Property Located in a Flood Zone," Mortgagecalculator.biz, accessed January 31, 2019, https://www.mortgagecalculator.biz/c/flood-zones.php.

they felt at home.[26] This sense of security was destroyed after the storm, a number of individuals living there found evacuation impossible owing to lack of transportation and the high cost of relocation; due to the circumstances, most housing issued in this area was the notorious FEMA travel trailers, which themselves added to the burden felt. Ten years after the storm, the neighborhood still had not seen major signs of recovery. A lack of services, schools, businesses, and other gathering places led several residents to abandon the area, seeking new ground to plant their roots, leaving their social networks behind.[27] As Hurricane Katrina came through in 2005, the residents lost more than just houses full of possessions, they lost the support system they had in each other – they lost their microculture, and with that, many lost hope for the future.

In a survey conducted by HUD, 51% of respondents were in better housing post-Katrina and 35% lived similarly to how they had before the storm, while nearly 20% were living in shared spaces with other households and 12% were left without a home of their own. This same survey reveals that the average income of those responding was US$18,500 and 44% were spending over half of their income on rent. It was also found that 67% of survey respondents did not have full time employment. HUD established from this

[26] Rich Binsacca, "Case Study: Starting Over in the Lower Ninth Ward" (Architect Magazine, 2011), https://www.architectmagazine.com/technology/case-study-starting-over-in-the-lower-ninth-ward_o.
[27] W A Lascell and P R Baumann, "LOWER 9th WARD, NEW ORLEANS: RECOVERY AND REBUILDING," vol. 48, 2015, 38, https://msaag.aag.org/wp-content/uploads/2015/09/4-Lascell-and-Baumann-MSG482015F.pdf.

survey that encouraging self-sufficiency by fostering job-skills training may provide more long-term stability for victims.[28]

The immortal trailer. In 2008, FEMA started pushing to get people out of the trailers located in commercial parks and those managed by the agency and into more permanent housing solutions, though it took until 2012 for the removal of the last trailer from New Orleans.[29] In an effort to recover some of the money spent on the trailers, FEMA sold many of them through the General Services Administration in 2010 with warning notices per HUD regulations, making buyers aware of potential health hazards.[30] Many of the buyers were recreational vehicle (RV) dealers, failing to pass on the warning to their trusting consumers, bringing about a new generation of Katrina victims.[31] The question of what is to be done with the units after their second life remains.

What changed. Having caused millions of dollars in lawsuits, re-housing, and health expenses, the decisions made in the aftermath of Hurricane Katrina have continued to haunt the country and its citizens for over 13 years, despite every effort to correct the initial mistakes made after the storm. In 2008, the National Response Framework (NRF), a more robust set of standards that built upon the lessons learned following Katrina, replaced the NRP.[32] Perhaps the

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[28] US Department of Housing and Urban Development, "Post-Katrina Disaster Housing Assistance and Household Transition," 2007, https://www.huduser.gov/portal/pdredge/pdr_edge_research_041913.html.
[29] The Associated Press, "New Orleans' Last Hurricane Katrina FEMA Trailer Leaves City," NOLA, 2012, https://www.nola.com/katrina/index.ssf/2012/02/new_orleans_last_hurricane_kat.html.
[30] US General Services Administration, "Public Sales of Hurricane Katrina/Rita FEMA Trailers: Are They Safe or Environmental Time Bombs?," 2010, https://www.gsa.gov/node/77831.
[31] Mary Mueller, "Post Katrina FEMA Trailers Still Being Sold?," BRPRoud.com, 2016, https://www.brproud.com/news/local-news/post-katrina-fema-trailers-still-being-sold/365421105.
[32] US Department of Homeland Security, "National Response Framework," *Foundations of Homeland Security: Law and Policy*, 2011, https://doi.org/10.1002/9780470925805.ch21.

most important change implemented in the NRF is the holistic nature of the framework. It calls upon resources and services from the communities affected to accomplish true resilience in the face of disaster. By staying local and involving residents, the immediate needs of the community can be understood and addressed in a more effective way than was previously done using the NRP.

Communication and preparedness are repeated themes throughout the new framework, having non-governmental organization involvement in training volunteers, identifying emergency shelter locations, providing health services, and assisting in breeching language barriers; and providing informational resources such as www.ready.gov for individuals to take measures toward preparedness at a household level. There are five mission areas highlighted in the NRF: Prevention, Protection, Mitigation, Response, and Recovery. Within the Response mission is the Mass Care Services core capability, coordinated by the Department of Homeland Security and FEMA, which involves planning for and providing housing solutions, counseling assistance, and employment resources, among other services, for those victims who are unable to return to their homes.[33]

In 2011, the National Disaster Recovery Framework (NDRF)[34] was created as a companion to the NRF, serving the purpose of expanding on long-term community recovery post-disaster and reducing vulnerability to future

[33] US Department of Homeland Security, "Emergency Support Function #6-Mass Care, Emergency Assistance, Housing, and Human Services Annex," 2008, https://www.fema.gov/pdf/emergency/nrf/nrf-esf-06.pdf.
[34] US Department of Homeland Security, "National Disaster Recovery Framework," 2011, https://www.fema.gov/pdf/recoveryframework/ndrf.pdf.

tragedies. This expansion includes nine principles for effective recovery: Individual and Family Empowerment, Leadership and Local Primacy, Pre-Disaster Recovery Planning, Partnerships and Inclusiveness, Public Information, Unity of Effort, Timeliness and Flexibility, Resilience and Sustainability, and Psychological and Emotional Recovery. The principle of Resilience and Sustainability in the NDRF highlights the importance of rebuilding a community which focuses on long-term security by designing a dynamic system of interdependent duties; suggesting that by treating the operation holistically, a more thorough economic, environmental, and social recovery can begin to take place. Due to the lasting effect of Katrina, the nation's leaders set into motion this series of important changes that would come to be tested several times over, though perhaps most thoroughly in 2017 after Hurricane Harvey struck Houston, Texas in late August.

Hurricane Harvey

The storm. Despite being founded nearly 120 years later, the culture in Houston is much like that of New Orleans; the residents love their city and believe in their ability to ride out anything that comes their way. This disposition is evident upon looking at the early history of both cities. Only four years after Jean-Baptiste Le Moyne founded Nouvelle-Orléans, a hurricane struck, demanding the new city be rebuilt.[35] Similarly, Houston, being built on swampland, has struggled with flooding since its inception, leading residents to

[35] History.com editors, "New Orleans - HISTORY" (A&E Television Networks, 2010), https://www.history.com/topics/us-states/new-orleans.

hurriedly start draining the land with little planning.[36] Unfortunately, nature proved once again that it cannot be tamed.

The storm that would become Hurricane Harvey began in the mid-Atlantic, north of Brazil, on August 16, 2017. It pathed its way through the Caribbean Sea and up through the Gulf of Mexico, hitting just north of Corpus Christi, Texas, at its peak of a Category Four hurricane on August 25.[37] Despite the storm's rapid decline in intensity, weakening to a tropical storm only 12 hours after touching land, the storm hovered in the Gulf for three days, dumping a historic 51.88 inches (131.77 centimeters) on the Greater Houston area.[38] Harvey was one of the costliest hurricanes in US history, second only to Katrina, causing a total of US$125 billion in damage (in 2017).[39] According to the *Houston Chronicle*[40] of the 204,000 homes damaged, nearly 75% of them were outside of the 100-year flood plain.[41] It was found that those neighborhoods within the 100-year flood plain suffered a devastating blow.[42]

Agency response and housing the displaced. The governor of Texas requested temporary housing from FEMA on September 7 to assist those

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[36] Daphne Thompson, "Houston's History of Floods," WeatherOps, 2017, https://blog.weatherops.com/houstons-history-of-floods.
[37] National Oceanic and Atmospheric Administration, "Historical Hurricane Tracks."
[38] Robert Morast, "Hurricane Harvey by the Numbers," Houston Chronicle, 2017, https://www.houstonchronicle.com/life/article/Hurricane-Harvey-by-the-numbers-12172287.php.
[39] National Hurricane Center, "Costliest US Tropical Cyclones."
[40] David Hunn, Matt Dempsey, and Mihir Zaveri, "In Harvey's Deluge, Most Damaged Homes Were Outside the Flood Plain, New Data Show" (Houston Chronicle, 2018), https://www.houstonchronicle.com/news/article/In-Harvey-s-deluge-most-damaged-homes-were-12794820.php.
[41] A 100-year flood plain describes an area which has a 1% chance of flooding in one year.
[42] Harris County FEMT, "Harris County Flood Education Mapping Tool" (Harris County Flood Control District, 2018), http://www.harriscountyfemt.org/.

affected, though the first license permitting the placement of temporary housing took a full month to approve.[43] Due to miscommunication and a lack of coordination between federal and state governments, it took four months from the governor's request for FEMA to provide trailers to those who were able to qualify, despite complications that many victims had in meeting the minimums for assistance. Almost 7,000 households qualified for temporary housing, though in January 2018, over 5,800 remained in queue for assistance. Some residents who did receive their long-awaited trailers were forced to stare at the immaculate new housing units for weeks before being allowed to move in because of delays for inspection and utility hookup.[44]

Kashmere Gardens. Among the most affected communities in Houston after Hurricane Harvey was the tight-knit, predominantly Black neighborhood of Kashmere Gardens, a place not unlike the Lower Ninth Ward in New Orleans in population or circumstance. The neighborhood population was estimated to be 17,465 in 2017.[45] The median household income in 2016 was US$24,616,[46] compared to Houston's much higher average income of US$47,010.[47] The Social Vulnerability Index map of the neighborhood shows an overall score of

[43] The Katy News, "Harvey Timeline," 2018, http://thekatynews.com/2018/08/08/harvey-timeline/.
[44] Robert Arnold, "FEMA Trailer Frustrations Linger Four Months after Harvey" (Click2Houston.com, 2018), https://www.click2houston.com/news/fema-trailer-frustrations-linger-four-months-after-harvey.
[45] U.S. Census Bureau, "2013-2017 American Community Survey Total Population 5-Year Estimates: Tract 2108/2109/2110/2112/2117/2302," accessed March 29, 2019, https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_17_5YR_B01003&prodType=table.
[46] Niche.com, "Kashmere Gardens," accessed November 4, 2018, https://www.niche.com/places-to-live/n/kashmere-gardens-houston-tx/residents/.
[47] Niche.com, "Houston, TX," accessed November 4, 2018, https://www.niche.com/places-to-live/houston-harris-tx/.

0.9172.[48] According to a FEMA data analysis done by Amelia Adams, a Texas Housers equity analyst, the highest concentration of victims with unmet housing needs post-Harvey were disproportionately located in low-income neighborhoods and communities of color, such as Kashmere Gardens.[49]

While hurricanes can't target areas by income class, neighborhoods like Kashmere Gardens rely on community, organizations, and government services in order to recover. Similar to what happened in New Orleans after Katrina, more affluent areas of Houston recovered more quickly. Low-income neighborhoods are at a disadvantage due to limited savings and a lower likelihood to carry flood insurance. A major roadblock that many low-income victims faced in acquiring post-Harvey relief from the government was a minimum qualification of US$17,000 of damage done to their properties. While US$17,000 worth of damage could be a small percentage for someone living in an upper-middle-class neighborhood, it could amount to over 50% of another person's manufactured home.[50] Using an arbitrary dollar amount as a minimum qualification instead of a percentage is an obvious injustice suffered by the poor. While many low-income victims were unable to qualify for assistance, several cases of fraudulent activity were reported where residents without storm damage received money; in one of these cases, over US$115,000

[48] Centers for Disease Control, "Social Vulnerability Index."
[49] Christina Rosales, "Greatest Concentration of Unmet Hurricane Harvey Housing Need in Harris County Is in Low-Income Communities of Color," Texas Housers, 2018, https://texashousers.net/2018/01/04/highest-unmet-housing-need-in-harris-county-after-hurricane-harvey-is-in-low-income-communities-of-color/.
[50] Marina Starleaf Riker, "Almost 2,600 FEMA Trailers, RVs Sit Unused in Beeville," Victoria Advocate, 2018, https://www.victoriaadvocate.com/news/almost-fema-trailers-rvs-sit-unused-in-beeville-w-video/article_80e2bc5c-38e8-11e8-9b91-07c43f9ffa20.html.

was paid to an undeserving recipient.[51] This activity demonstrates how processes have not shown as significant improvement as would be expected in the years since Hurricane Katrina.

As of October 2018, there were still several hundreds of victims of Hurricane Harvey that were living in government provided relief housing. R.A. Schuetz of Beaumont Enterprise mentions the number amounted to as many as 1,800 households living in FEMA trailers over a year after the storm with only four months remaining before assistance was to be terminated and the units removed. These victims' homes remained unlivable; the circumstances forcing them to face homelessness in the wake of ineffectiveness still thick within government recovery programs.[52] These are the failures for which this research attempts to find solutions.

1.2 Approach

Energy and water are necessities of daily life and critical factors in recovery and reintegration into society after a disaster. This study evaluates CO_2 output from trailers and considers cleaner, more accessible avenues for providing a much-needed supply of power for those living in relief housing. Water collection and reuse options are also evaluated to avoid delays in utility hookups and restricted placement of units. Additionally, the total expense of

[51] US Attorney's Office, "Five Charged in Fraud Schemes Linked to Hurricane Harvey," 2018, https://www.justice.gov/usao-sdtx/pr/five-charged-fraud-schemes-linked-hurricane-harvey.
[52] R.A. Schuetz, "Many Harvey Victims Remain out of Homes," Beaumont Enterprise, 2018, https://www.beaumontenterprise.com/news/article/Many-Harvey-victims-remain-out-of-homes-13347784.php.

the disaster relief housing decisions made by FEMA is approximated and shown alongside an estimated cost for using off-grid tiny houses for storm victims. Criteria provided by the World Health Organization for acceptable levels of formaldehyde exposure is compared to amounts found in FEMA trailers, allowing an understanding of one of the major health concerns raised by victims of Hurricane Katrina. Understanding how living environment affects mental health is another important aspect of recovery and is considered as an area of concern that needs to be addressed. A comparative analysis is performed to determine the impact of the trailers used by FEMA against tiny house alternatives. The main areas of focus are the expense in US dollars, the impact to the environment in the form of CO_2 emissions from energy usage, and the physical and mental health of storm victims regarding relief housing and recovery. After establishing an understanding of what areas of post-disaster housing were successful and what needs improvement, concepts are presented as a solution to areas of concern.

Evaluating the progress made throughout FEMA's history of handling post-disaster recovery and performing the cost comparisons to the proposed alternative, this research discusses the lessons yet to be learned. The report written by the World Commission on Environment and Development in 1987, titled "Our Common Future,"[53] defined sustainable development as "development that meets the needs of the present without compromising the

[53] World Commission on Environment and Development, "Report of the World Commission on Environment and Development: Our Common Future Towards Sustainable Development 2. Part II. Common Challenges Population and Human Resources 4," 1987, http://www.un-documents.net/our-common-future.pdf.

ability of future generations to meet their own needs." It is important to consider the future consequences of actions applied in times of need, being that if care is not taken to examine the implications of the decisions made today, further, more devastating problems could present themselves in time.

CHAPTER 2: LITERATURE REVIEW

2.1 Tiny Housing

Living Deliberately

Throughout history, tiny homes have been used as shelter for many cultures, called by different names such as pueblos, yurts, tipis, hogans, igloos, and earthen houses – all were designed for the climate in which they were used.[54] These ancient houses worked well for the people who lived in them: some were easy to put up and take down while others were more permanent, they were all made with locally sourced and natural materials, insulated and ventilated to support proper thermal regulation and air flow, and they kept community together.[55] As time progressed, the design and necessity of these dwellings changed, though the main concept remained the same – to maintain a sustainable, comfortable home with little negative impact to the land on which it was built.

Henry David Thoreau is often touted as the first advocate of what would become known today as the Tiny House Movement. His years at Walden Pond in 1854 opened his eyes to the concept of essentialism and the effect of being surrounded by nature. His cabin there was 150 square feet (13.93 square

[54] Native Languages of the Americas, "Native American Homes: Wigwams, Longhouses, Tepees, Lodges, and Other American Indian Houses," 2014, http://www.native-languages.org/houses.htm.
[55] Daniel Sjöberg, "15 Ancient House Designs That You Can Build Really Cheap (Potentially For Free)," Walden Labs, 2014, https://waldenlabs.com/ancient-shelters-you-can-build-cheap/.

meters),[56] much smaller than many of today's tiny houses.[57] He lived there for two years and two months discovering the freedom that living simply gave him. At the end of Thoreau's time in his tiny cabin, he left with a renewed sense of self and zest for life. By maintaining a self-sustaining home, with his time free of the worries of affording anything other than the "essential facts of life,"[58] he gained the liberty to focus on endeavoring in something much more profound. He believed that it is easy to fall into routine, and if left unchecked it can consume an entire lifetime, but that if given the opportunity to confidently follow one's passions, the effort will be met with success.[59] Thoreau was a reformist;[60] as an environmentalist and a minimalist, his views did not resonate well with the people of his time who were looking to grow cities and consume as quickly as was possible. He reflected on the idea that people should pursue their own way, relying less on debt to others and creating a more self-sufficient and meaningful existence.

Judith Saunder's entry in "Henry David Thoreau's 'Walden'" explains Thoreau's view of economics not as the amount of commodities to which one can assign a dollar-value but as the "limited amount of time, energy, and attention, which may be conserved, saved, spent, employed, stolen,

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[56] Henry David Thoreau, *Walden* (Ticknor and Fields, 1854), 58.
[57] Tiny houses are generally less than 250 square feet (23.23 square meters) but can measure up to 400 square feet (37.16 square meters).
[58] Thoreau, *Walden*, 87.
[59] Thoreau, 249.
[60] Ashley Newman, "Biography: Henry David Thoreau: Ahead of His Time?" (Vision.org, 2017), http://www.vision.org/henry-david-thoreau-biography-5887.

squandered, or hoarded – just like property."[61] Samuel Alexander, a writer involved with *The Simplicity Collective*, reinforces this in his work "Just Enough is Plenty: Thoreau's Alternative Economics," not only by writing of the exchange of time and energy for goods but also how purchases hold power and simplicity has the ability to challenge capitalism.[62]

Size Matters

The Department of Environmental Quality in the state of Oregon evaluated the environmental benefits of reducing material use during the design, construction, maintenance, and demolition of buildings.[63] The study reviewed four housing sizes ranging from extra small to large, finding the extra small home to have a 20-40% reduction in environmental impact compared to the medium sized home.[64] The results of this study also revealed that most potential benefits can be had in avoiding waste at the beginning of the life cycle. The study concluded that reducing housing size was among the best options for minimizing waste while also achieving a variety of environmental benefits. This study focused on decreasing the size of an average home, though it also found that increasing density and maintaining fewer possessions could present even better results.[65]

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[61] Judith P. Saunders, "Transcendental Capitalist at Walden," *Henry David Thoreau's "Walden,"* 1987, 59.
[62] Samuel Alexander, "Just Enough Is Plenty: Thoreau's Alternative Economics" (The Simplicity Collective, 2011), 80, www.SimplicityCollective.com.
[63] Quantis, Earth Advantage, and Oregon Home Builders Association, "A Life Cycle Approach to Prioritizing Methods of Preventing Waste from the Residential Construction Sector in the State of Oregon Phase 2 Report, Version 1.4-Executive Summary Land Quality Division," 2010, 1, https://www.oregon.gov/deq/FilterDocs/ADU-ResBldgLCA-Report.pdf.
[64] Quantis, Earth Advantage, and Oregon Home Builders Association, 5.
[65] Quantis, Earth Advantage, and Oregon Home Builders Association, 8.

Alex Wilson and Jessica Boehland performed a study on six houses in Boston, MA, and St. Louis, MO. Two of the houses were 3,000 square feet (278.70 square meters) with good energy standards, while four of the houses were 1,500 square feet (139.35 square meters) – two of them with good energy standards and two with poor standards. Wilson and Boehland found that even the smaller houses with poor energy standards out-performed the well-insulated large houses in both heating and cooling cost and amount of energy used.[66] This suggests that dwelling size will always have a significant contribution to cost as well as impact the unit has on the environment.

2.2 Off-grid Technologies

Thermal Regulation

One of Frank Lloyd Wright's last contributions to American architecture was his vision of what he called the Usonian house, an affordable, comfortable home made with prefabricated materials that focused on simplifying thermal regulation, lighting, and sanitation.[67] Of Wright's Usonian designs, one of his more unique concepts was the Solar Hemicycle, first used in Jacobs II.[68] The Solar Hemicycle applied natural cooling and passive solar techniques, using

[66] Alex Wilson and Jessica Boehland, "Small Is Beautiful: US House Size, Resource Use, and the Environment," *Journal of Industrial Ecology* 9, no. 1 (n.d.): 279, 282.
[67] Jackie Craven, "About the Usonian Vision of Frank Lloyd Wright," ThoughtCo, 2018, https://www.thoughtco.com/usonian-style-home-frank-lloyd-wright-177787.
[68] JM Syken, "Solar Hemicycle: Frank Lloyd Wright's Jacobs II Passive Solar House" (PDH Online, 2014), 23, https://pdhonline.com/courses/c683/c683slideshow.pdf.

stone and earth to insulate from northerly winds and large windows oriented to let in as much sun as was possible, both for light and heat.[69]

In J. Morrissey, T. Moore, and R.E. Horne's study done on affordable passive solar design, it is mentioned that builders often argue the limitations of building orientation in utilizing this method of thermal regulation because it requires a larger portfolio of designs, creating additional cost.[70] However, the researchers have shown that by spending the extra time (i.e. money) in the design stage, a more versatile model can be constructed that performs at high energy efficiency across many different orientations thus reducing the need for an extensive portfolio and saving on cost.[71] Further, it was discovered that housing size was a critical component in determining performance, as a smaller unit size was found to be easier to consistently maintain energy efficiency across all models than larger model sizes.[72] This study ultimately concludes that in addition to providing housing with a lower environmental impact, saving money is possible through thoughtful design and innovation.[73]

Despite his unique utilization of passive design, the original concept does not belong to Frank Lloyd Wright or any of the modern architects who have been using these techniques since the early twentieth century; these natural methods of thermal regulation are something mankind has been using for

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[69] Syken, 28.
[70] J. Morrissey, T. Moore, and R.E. Horne, "Affordable Passive Solar Design in a Temperate Climate: An Experiment in Residential Building Orientation," *Renewable Energy: An International Journal* 36 (2011): 576, https://ac-els-cdn-com.ezproxy.lib.ou.edu/S0960148110003836/1-s2.0-S0960148110003836-main.pdf?_tid=6a65f0ef-eb82-4b09-8320-a55d580a5278&acdnat=1546987215_204327bf76791ef35ae6e0bcd8aaaa61.
[71] Morrissey, Moore, and Horne, 576.
[72] Morrissey, Moore, and Horne, 574.
[73] Morrissey, Moore, and Horne, 571.

thousands of years, as John Perlin indicates in *History of Solar Energy*. In ancient Greece, the cities of Colophon, Olynthus, and Priene were designed in such a way to allow every resident access to passive solar heating for their homes during the winter. The building orientation and design of these structures allowed every home to face south, exposing them to the low hanging sun in the colder months.[74] Perlin goes on to explain how the ancient Romans improved upon the usage of passive solar by adding mica or glass to south-facing windows, allowing heat from the sun to become trapped in the building, as heat is unable to easily escape through the glass window coverings.[75] Across the ocean, in Indigenous America, native people were experimenting with the same technologies. The Pueblo people, who have been living in Acoma since the 12th century, located in what is now New Mexico, built stacked units allowing exposure to the southern sun in the same way the ancient Grecians and Romans oriented their structures. The houses were constructed out of adobe, a brick made from earth and natural materials, allowing heat to work its way slowly into the home as night approached.[76] As Perlin has shown in his study, these ancient cultures have proven throughout history the effectiveness of passive solar energy, allowing Frank Lloyd Wright and other contemporary architects to carry the tradition into modern centuries.

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[74] John Perlin, "History of Solar Energy," *Encyclopedia of Energy* 5 (2004): 607, https://ac-els-cdn-com.ezproxy.lib.ou.edu/B012176480X000358/3-s2.0-B012176480X000358-main.pdf?_tid=1db2d2b9-6de9-420c-a96c-88828f51c503&acdnat=1551446640_d7d857a35bc0a8368561553dad753430.
[75] Perlin, 607.
[76] Perlin, 608.

While harnessing heat is a critical component of passive design, design strategy for cooling plays a pivotal role as well, especially in regions that are typically very hot. According to a study done by Lapisa et al. in 2018, using a reflective surface to create a cool roof with an albedo of around 0.9 was found to be effective in maintaining summer comfort.[77] The same study found that using skylights has a positive impact during winter months, increasing solar heat gains. Conversely, they were found to have negative effects in summer months due to this same reason. Using skylights in the design of a passive building was found to be complex, needing to be kept at the correct area coverage for optimal comfort due to solar gain and natural night ventilation.[78] Light tubes can be used as an alternative to skylights, offering an option that provides light without contributing to heat gain.[79]

Carlos Ochoa and Isaac Capeluto, in their study on strategic decision-making for intelligent buildings, highlight the importance of design when considering passive and active features for buildings in hot climates. They consider the façade of a building to be one of the more crucial components of a design, relaying the importance of heat rejection, ventilation for comfort and cooling thermal mass, and sunlight control.[80] They found using passive design

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[77] R. Lapisa et al., "Optimized Design of Low-Rise Commercial Buildings under Various Climates – Energy Performance and Passive Cooling Strategies," *Building and Environment* 132 (2018): 90, https://ac-els-cdn-com.ezproxy.lib.ou.edu/S0360132318300416/1-s2.0-S0360132318300416-main.pdf?_tid=9cb9db05-f5d0-4d56-a098-a0ba82861f0b&acdnat=1552173274_37aa8cca9ea25e2f605a8010ec2cd911.

[78] Lapisa et al., 91.

[79] "Designing Energy Efficient New Homes for a Warm Climate," eXtension, 2014, https://articles.extension.org/pages/26272/designing-energy-efficient-new-homes-for-a-warm-climate.

[80] Carlos Ernesto Ochoa and Isaac Guedi Capeluto, "Strategic Decision-Making for Intelligent Buildings: Comparative Impact of Passive Design Strategies and Active Features in a Hot Climate," *Building and Environment*

on its own to show positive results in efficiency, however, they noted there were some disadvantages due to lack of user control. Their results showed that the combination of passive design strategies with active controls, such as lighting dimmers and redirection, gave consistent energy savings in their simulations.[81] Ochoa and Capeluto suggest that in the architectural design process, the more specialists that are involved early on to solve potential problems and offer their expertise, the better the outcome of the building performance could be, noting that changes become more expensive and difficult as the project advances.[82]

Water Catchment

Living off-grid presents several challenges, one of the most critical being the sourcing, collection, and storage of water. Although much like tiny houses and passive solar, ancient technology lends some wisdom for accomplishing this feat. The ancient Romans used rainwater harvesting (RWH) on a massive scale, using aqueducts to supply water to entire cities. However, as Jan Gerston points out, one of the most appealing aspects of RWH is its flexibility.[83] This method of collection can be as complex or as simple as desired, whether in permanent structures, integrated fully into an underground filtration system, or in a temporary setting, using easily transportable materials. Gerston simplifies the process: to have a fully functional RWH system, one needs a

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43 (2008): 1831, https://ac-els-cdn-com.ezproxy.lib.ou.edu/S0360132307002090/1-s2.0-S0360132307002090-main.pdf?_tid=d5d12abd-55d7-4ce4-b10d-50874cc29f15&acdnat=1552172476_5a16a2b9c7709d26622668523270fb0e.

[81] Ochoa and Capeluto, 1838.

[82] Ochoa and Capeluto, 1830.

[83] Jan Gerston, "Rainwater Harvesting: A New Water Source," *Texas Water Savers*, vol. 3, 1997, 2, http://twri.tamu.edu/newsletters/texaswatersavers/tws-v3n2.pdf.

catchment area along with gutters and downspouts to channel the water into a cistern; through a conveyance system, the water can be pumped into a final area where it is treated and made ready for use.[84]

Net-zero Water Treatment

Research by Janet Leong et al. shows that rainwater harvesting can be used in conjunction with greywater recycling, creating a closed-loop system.[85] Greywater is water that has been gently utilized (e.g. bathroom sinks, showers, washing machines) and blackwater is water that has been used for biological or organic waste (e.g. toilets, kitchen drains) – this is wastewater that is no longer viable for use in its current state. Using a greywater recycling system can reduce the environmental impact of household water requirements by utilizing available water rather than creating demand for water treated off-site in a facility. Leong et al. caution against using untreated greywater and note that combining rainwater with greywater results in a mixture that should be treated as greywater needing to be fully treated before use.[86]

[84] Gerston, 3:2.
[85] Janet Yip Cheng Leong et al., "Prospects of Hybrid Rainwater-Greywater Decentralised System for Water Recycling and Reuse: A Review," *Journal of Cleaner Production* 142, no. 4 (2017): 3024, https://ac-els-cdn-com.ezproxy.lib.ou.edu/S095965261631798X/1-s2.0-S095965261631798X-main.pdf?_tid=9cd77e19-1120-4f6d-9778-75a4a4dd8287&acdnat=1551710168_983103c67804b856ee1a6e0096109dbc.
[86] Leong et al., 3025.

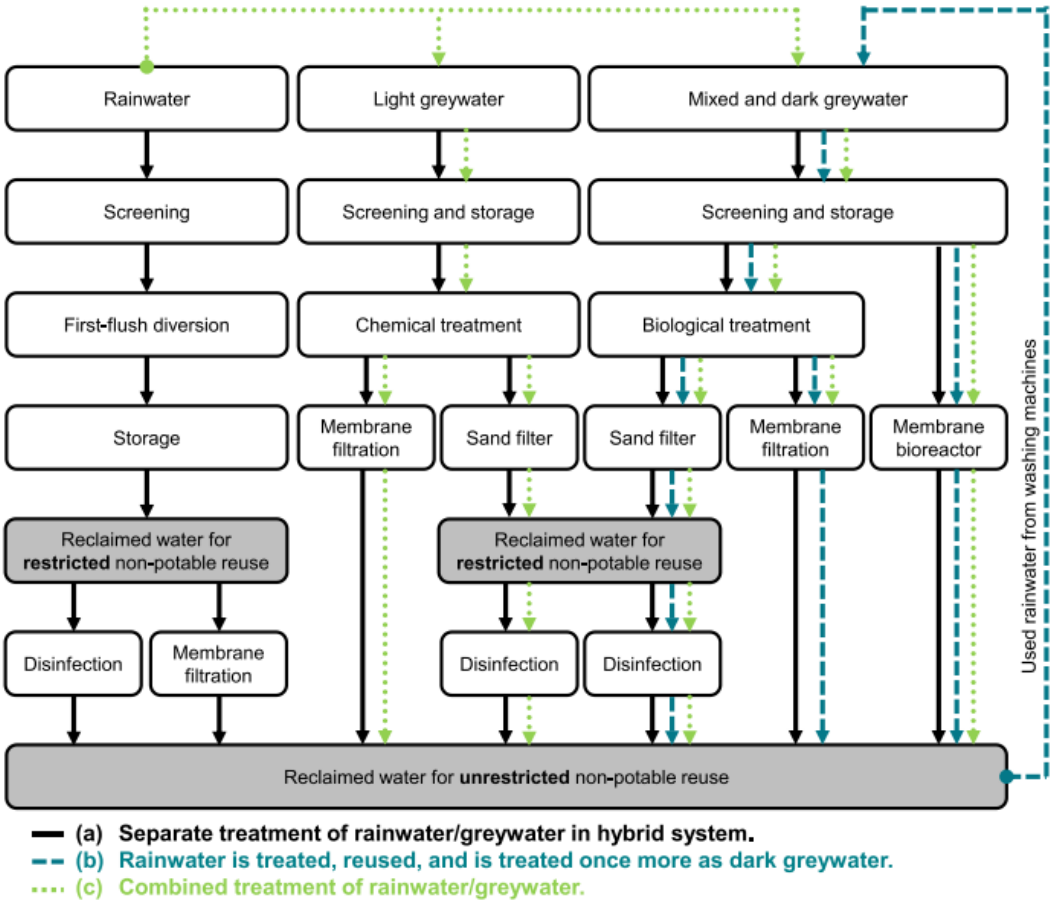

Figure 1. Hybrid rainwater-greywater system design. Leong et al., Proposed hybrid rainwater-greywater system designs, 2017, in Journal of Cleaner Production 142.[87]

Treatment of wastewater is important to consider when developing communities that are not connected to a city sewer system or septic due to the number of contaminants that could be introduced into the environment. Net-zero greywater (NZGW) reuse is a mostly closed-loop system that can treat water to its original state, allowing for reuse.[88] While there are many

[87] Leong et al., Proposed hybrid rainwater-greywater system designs
[88] Lucien W Gassie and James D Englehardt, "Advanced Oxidation and Disinfection Processes for Onsite Net-Zero Greywater Reuse: A Review," *Water Research* 125 (2017): 385, https://doi.org/10.1016/j.watres.2017.08.062.

applications of greywater reuse in non-human contact scenarios such as that proposed by the hybrid system Leong et al. illustrated in their research, NZGW reuse aims to allow for human contact uses such as bathing.[89]

Lucien Gassie and James Englehardt, in their study titled "Advanced Oxidation and Disinfection Processes for Onsite Net-Zero Greywater Reuse: a Review," found that an Ozone-UV treatment is an energy efficient method of disinfection that could allow for compliance with health and safety standards without a secondary disinfection process needing to be applied, although the researchers mentioned that both chlorination and ozone may be used as a secondary disinfection method for on-site reuse application.[90] The study also provides an answer for the provision of low-energy hot water. It is stated that greywater contains the same thermal energy as that of municipal wastewater without the need for heat pumping, heat exchange, or energy conversion.[91]

The International Space Station is taking advantage of water recovery systems designed to sanitize and reuse urine and perspiration, cycling it back as potable water in a closed-loop.[92] This technology is also being put to use in Kendala, a small village in Iraq, that had been struggling to find a source of water clean enough for human consumption.[93] While a single-family, residential scale NZGW reuse system may not be commercially available for

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[89] Gassie and Englehardt, 385.
[90] Gassie and Englehardt, 396.
[91] Gassie and Englehardt, 385.
[92] Meghan H Oliver, "Slaking Astronauts' Thirst in Zero Gravity," *Natural Science Collection Pg*, vol. 43, 2006, 1, https://search-proquest-com.ezproxy.lib.ou.edu/docview/201452490/fulltextPDF/B23932C65649489EPQ/1?accountid=12964.
[93] Oliver, 43:2.

some time, a Swedish company by the name of Orbital Systems has developed a closed-loop shower inspired by the water recycling system designed by Industrial Designer Mehrdad Mahdjoubi for use in the Mars Mission project by the National Aeronautics and Space Administration.[94] The fixture is currently on the market and saves up to 90% of water and 80% of the energy used while treating and recirculating water in real time, removing particles and neutralizing bacteria using two purification technologies,[95] proving the concept to be effective and applicable in daily use. The advantages to using a closed-loop system for water recycling is the ability to have a reliable water supply where clean water is lacking. Utilizing a system such as this also cuts back on the amount of storage needed in an RWH system.

2.3 The First Crusaders

Katrina Cottage

Due to a perfect storm of poverty, uninsured homes, and inefficient planning and coordination after Hurricane Katrina, over a decade later, people are still trying to find their way home. Designers, architects, and philanthropists across the country saw this need for a better solution as early as a few months after Katrina and began stepping up to the plate. The Katrina Cottage was a project that became a movement, created by Andrés Duany at the Mississippi Renewal Forum in 2005; it united designers and architects in

[94] "Orbital Systems," Orbital Systems, accessed March 6, 2019, https://orbital-systems.com/company/.
[95] "Digital Recirculating Shower System," Orbital Systems, accessed March 6, 2019, https://orbital-systems.com/product/.

an effort to develop livable, transitional housing for displaced victims of Hurricane Katrina. Duany's vision was to incorporate long-term, small-scale, affordable relief housing into real neighborhoods, allowing victims to feel included in established communities rather than being isolated in a storm-havocked wasteland.[96] Marianne Cusato's "little yellow house" was the champion of the movement, winning the People's Choice Award at the Cooper-Hewitt National Design Awards.[97] Her aesthetically pleasing and space efficient 308 square foot (28.61 square meter) cottage had a build cost of US$35,000. Though Cusato's tiny house may have been an early favorite, it was only one small drop in a tidal wave of innovative designs, each smarter and more efficient than the last.[98]

However, when the Katrina Cottages were offered to FEMA as a solution, the agency was not receptive. They did not want to get involved with permanent dwellings, arguing that it was outside of the scope of their purpose and would be better left for HUD. Given that FEMA was still in the thick of dealing with the fiasco of managing post-Katrina relief housing with the limited knowledge they had, it was understandable that they had no intention of taking on this responsibility without pushback. Steve Mouzon led the battle for getting the Katrina Cottages put into use and was able to get US$0.5 billion approved by

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[96] Ben Brown, "The Katrina Cottage Story: Tiny Cottages Become a Growth Industry" (Mississippi Renewal Forum, 2006), http://mississippirenewal.com/info/dayAug23-06b.html.
[97] Cooper-Hewitt, "People's Choice Award: Marianne Cusato," The National Design Awards Gallery, 2006, http://ndagallery.cooperhewitt.org/MarianneCusato.
[98] Ben Brown, "Katrina Cottage Unveiled: Affordable Cottage a Hit at Builders' Show" (Mississippi Renewal Forum, 2006), http://mississippirenewal.com/info/dayJan-11-06.html.

Congress for permanent installation. Unfortunately, miscommunication within the Forum led to mismanagement of the money for this project and the effort was split apart into several smaller operations.[99]

As functional as the first generation of Katrina Cottages were, Mouzon continued the design process, seeking more areas for improvement. He drafted a new model to address the need for growth when returning to normality after the crisis of disaster. In his book, "The Original Green (Unlocking the Mystery of True Sustainability),"[100] he acknowledges that many people are hesitant to accept tiny homes and often need to be convinced of their merits. Attempting to showcase the functionality of tiny homes, he called his revised concept the Smaller & Smarter Cottage. His design incorporates more storage per square foot by using space in creative ways and is also capable of expansion into a more comfortable size, allowing a better solution for people hoping for more permanent accommodations. Mouzon called this second generation of Katrina Cottage the Katrina Kernel Cottage due to its ability to grow outward from a small seed home. When Mouzon brought his design to a manufacturer, he was made aware of several challenges that would bring mass production to a halt before it got started. The current culture of mobile home building is not suited for the type of housing Mouzon proposed. The CEO of the company he approached told him that his houses were so different that they would require

[99] Steve Mouzon, "What Was Gained in the Katrina Cottage Loss?," Original Green, 2015, http://www.originalgreen.org/blog/2015/what-was-gained-in-the.html.
[100] Steve Mouzon, *The Original Green (Unlocking the Mystery of True Sustainability)* (New Urban Guild Foundation, 2010), chap. 2.

new materials, new factories, and a new workforce with a new mindset. These differences, he said would be "an investment of millions of dollars."[101] These revelations led to the birth of studioSky, a design firm Mouzon shares with Eric Moser and Julia Sanford. Employing a new workforce with a new mindset, their mission is the implementation of the sustainable, innovative concepts that they had been told were impossible to get off the ground.[102]

Make It Right

The Make It Right (MIR) Foundation, spearheaded by actor Brad Pitt in 2007, was another endeavor that aimed to create homes for people affected by Hurricane Katrina, particularly in the Lower Ninth Ward. The 1,400 square foot[103] (130.06 square meter) homes provided by MIR cost an average of US$150,000,[104] providing a significantly bigger and more expensive solution than proposed by other initiatives. The mission of the organization was to provide high-quality, safe homes that create little impact to the environment.[105] Their intention was to use a cradle-to-cradle[106] approach to ensure that all stages of design were sustainable and recyclable; these homes used renewable energy and were designed for easy disassembly.[107] Additionally, MIR committed

[101] Mouzon, "What Was Gained in the Katrina Cottage Loss?"
[102] studioSky, "Ideals," accessed December 5, 2018, http://www.studiosky.co/ideals/.
[103] Make It Right, "Where We Work," accessed December 4, 2018, http://makeitright.org/where-we-work/new-orleans/.
[104] Make It Right, "Frequently Asked Questions," accessed December 4, 2018, http://makeitright.org/about/faq/#q4.
[105] Make It Right, "About," accessed December 4, 2018, http://makeitright.org/about/.
[106] Cradle-to-cradle is a life cycle approach to design created by Michael Braungart and William McDonough which creates a closed-loop system with the goal of eliminating all waste through reuse and recycling.
[107] Make It Right, "Cradle to Cradle," accessed December 4, 2018, http://makeitright.org/c2c/.

to building to Leaders in Energy and Environmental Design (LEED) Platinum certification standards, the highest the program maintains. To achieve LEED Platinum status, a building must have at least 90 points in eight categories for building practices such as sustainable siting, energy efficiency, and indoor air quality[108] - attributes that were all greatly needed in lieu of the toxic trailers offered immediately after the storm.

While John C. Williams, the executive architect hired by the foundation, did succeed in achieving LEED Platinum status, creating energy efficient and affordable designs, several of the homes were showing signs of decay only a year after construction, leaving Williams faced with the harsh reality of building in New Orleans, despite being local to the area. Moisture is a constant in the region and the new homes were not able to hold up to the climate, demonstrating the importance of extensive research to know what challenges are to be encountered in order to develop solutions that stand the test of time. Several lawsuits came about due to problems with black mold, sagging porches, roof leakages, water accumulation, and failing HVAC systems, calling for the foundation to return to the area to make it right, again.[109]

Many of the problems with the houses were due to the use of TimberSIL,[110] a wood product infused with glass, promoted as an eco-friendly,

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[108] Village Green Homes, "LEED Platinum Certification Categories and Point System Explained," accessed December 6, 2018, http://blueberrypdx.com/leed-certification.htm.
[109] Katy Reckdahl, "Closer Look at 'Make It Right' Homes at Center of Lawsuit against Brad Pitt Foundation" (The Advocate, 2018), https://www.theadvocate.com/new_orleans/news/article_258e70e8-b5e4-11e8-95d0-030296bbc61f.html.
[110] TimberSIL Products, "TimberSIL GlassWood Fusion Products," 2011, 1, www.timbersilwood.com.

non-toxic way to prevent water, heat, and insect damage without the use of chemicals. Although the foundation switched to using yellow pine in 2010 prior to any mention of a problem,[111] at least thirty-nine houses had been constructed using the defective material. Make It Right returned to the Lower Ninth in 2014, spending approximately US$12,000 per home replacing the TimberSIL; the foundation then sued the manufacturer in 2015 for US$500,000 for its false claims of having a reliable product. However, the money spent fixing the mistake was not enough to repair the damage and many residents felt as though MIR left them with expensive renovations they could not afford to fix, leading them to abandon the homes and seek out safer places to live.[112] [113]

Lowernine.org

In 2007, Rick Prose founded Lowernine.org after realizing that unskilled volunteers could rebuild homes effectively with little supervision. The organization has rebuilt 88 homes in the neighborhood and renovated over 200 homes.[114] The organization's website boasts an accomplishment of having brought back "more Lower Ninth Ward families than any other single organization," though it does note that many of the residents are new to the

[111] Matt Hickman, "Nontoxic Treated Wood Used in Make It Right Homes Starts to Rot," Mother Nature Network (The Advocate, 2014), https://www.mnn.com/your-home/remodeling-design/blogs/nontoxic-treated-wood-used-in-make-it-right-homes-starts-to-rot.
[112] Insurance Journal, "Lawsuit Planned Against Brad Pitt Foundation over New Orleans Homes," 2018, https://www.insurancejournal.com/news/southcentral/2018/08/31/499921.htm.
[113] Chris White, "Brad Pitt's Hurricane Katrina Homes in Louisiana Are Falling Apart" (News.com.au, 2018), https://www.news.com.au/lifestyle/home/outdoors/brad-pitt-slammed-over-rotting-homes-in-new-orleans/news-story/32a9a48316951567479c10cf25737f8e.
[114] "About," lowernine.org, accessed April 11, 2019, https://lowernine.org/about/.

area, buying land as it increases in value which has forced pre-Katrina residents out. Despite the unfortunate gentrification of the area, which is another issue that deserves attention, the organization has proven that local effort by volunteers has been an effective strategy for rebuilding.

2.4 Tiny Concepts

A Tiny Prototype

Jessica Gjerde, an architectural engineering major, led a project conducted by a team of student engineers at the University of Kansas, crafting a tiny house model for use in temporary housing for disaster relief.[115] The team consisted of a variety of students from different engineering backgrounds such as aerospace, mechanical, electrical, architectural, civil, chemical, and computer science and information technology.[116] This team of multidisciplinary minds worked together to solve many of the timing delays faced in post-hurricane housing. The model was designed for use in the absence of running water, utilizing amenities such as composting toilets and pump sinks to avoid the need for utility hookups, which has been a common delay in getting victims into FEMA-provided trailers. Andrew Williams, associate dean for diversity, equity, and inclusion, mentioned the panels for the houses are "modular and easy to put together," packaged similarly to IKEA furniture. The assembly

[115] KU News, "'Tiny House' Prototype Designed for Temporary Disaster Relief" (University of Kansas, 2018), https://news.ku.edu/tiny-house-prototype-seeks-provide-temporary-disaster-relief.
[116] Jessica Gjerde, "Tiny House for Disaster Relief" (YouTube, 2018), https://www.youtube.com/watch?v=_AcLW_9i0lM.

covers an area of 128 square feet (11.89 square meters) and includes a kitchen, bathroom, living space, and a loft for sleeping. Gjerde acknowledges that the space is small though preferable to homelessness or public shelter, in that it allows victims to have a place for themselves while rebuilding their lives.

Minimalist Relief House

Joseph Darnell Brown from Auburn University is another designer who promotes a minimalistic approach to emergency shelter.[117] He is critical of the trailers used by FEMA, noting the high formaldehyde levels due to mass production and circulation before materials were able to cure in addition to the added effects the Louisiana climate had on the issue.[118] He also acknowledges the difficulty in storing the trailers, their large footprint making them unable to be stored efficiently causing massive amounts of lot space to be taken by unused units.[119] Brown's 152 square foot[120] (14.12 square meter) design focuses on techniques that allow for off-grid placement. Providing an adequate number of windows allows for natural light to filter through the unit for use during the day and panels contain battery operated lighting for use at night.[121] Proper orientation of the unit allows for passive heating and cooling, relieving the structure of the need for electricity to regulate temperature.[122] A water

[117] Joseph D Brown, "A Minimalistic Approach to Adaptive, Emergency Relief Structures Embodied by Promoting a Downsized Way of Life" (Auburn University, 2013), https://etd.auburn.edu/bitstream/handle/10415/3705/Joseph D. Brown Final Thesis Document.pdf.
[118] Brown, 57.
[119] Brown, 58.
[120] Brown, 80.
[121] Brown, 101.
[122] Brown, 85.

catchment system supplies a reservoir for personal hygiene[123] while a chemical toilet is suggested as an inexpensive alternative to a composting toilet when water is scarce.[124] The panels of Brown's tiny house are structural insulated panels made of fiber-reinforced polymer and a CeraMix™ hard shell. This material is durable and waterproof in addition to being energy efficient, economical, and safe for the environment and human use.[125] Intended for temporary use they are designed to be modular; the unit can be shipped in a 4ft W x 8ft L x 6ft H (1.21m W x 2.43m L x 1.82m H) biodegradable box allowing for easy transportation, construction, deconstruction, storage, and reuse.[126] Brown estimates the cost of each unit to be US$909, making his design among the most cost-efficient proposals for disaster relief housing.[127]

Flex House

Like Gjerde and Brown, Kathryn Schenk is a proponent of prefabricated tiny housing, arguing that it offers an affordable, sustainable solution to urban sprawl and the reduction of waste.[128] Schenk observes several common factors in successful tiny housing: providing visual openness using large windows, having options and flexibility in design, access to the outdoors, utilizing vertical space efficiently, and using prefabrication and mass production to minimize cost.[129] In designing her Flex House, Schenk includes several important factors

[123] Brown, 97.
[124] Brown, 99.
[125] Brown, 83.
[126] Brown, 86.
[127] Brown, 77.
[128] Kathryn Schenk, "Flex House: Prefabricating the Tiny House Movement" (ProQuest, LLC., 2015), 44.
[129] Schenk, 68.

to be considered such as the ability to be assembled by a few people without heavy equipment and the integration of passive design and sustainable techniques. Her design is described as consisting of a "series of 4' x 8' panels on a grid that can be interchanged and adapted to accommodate a number of different functions."[130] The panels are crafted from high-quality materials and when assembled correctly create a highly efficient, insulated, and ventilated space that can be trusted to provide a comfortable, healthy, long-term living space.[131]

2.5 Design Approaches

There are numerous sustainable design approaches; those discussed in this research are the Integrated Design Approach that the Green Building Council uses in their LEED certification program to ensure all areas of the process are considered in the development of healthy, energy efficient buildings,[132] and the Okala Eco-design Strategy Wheel, a guide that is applicable to all aspects of design including manufacturing and use.[133] Using these strategies can help to establish a better approach to design and function of housing for disaster relief and recovery. Understanding the entire life of a housing unit, including materials, uses, and end-of-life can allow for a more

[130] Schenk, 46.
[131] Schenk, 58.
[132] Sherry Bonelli, "The Key to LEED Project Success – The Importance of a LEED Integrated Design Approach," 2012, http://succeedatleed.com/2012/02/the-key-to-leed-project-success-the-importance-of-a-leed-integrated-design-approach/.
[133] Philip White, Louise St. Pierre, and Steve Belletire, "Okala - the Ecodesign Strategy Wheel," *Okala Practitioner: Integrating Ecological Design*, 2013, http://www.okala.net/Okala Ecodesign Strategy Guide 2012.pdf.

efficient process of getting hurricane victims into and out of the units as smoothly as possible.

Integrated Design Approach

The Integrated Design Process (IDP) focuses on holistic design concepts that help to create sustainable buildings.[134] Two of the key topics of IDP are

- Integrated Project Delivery
- Integrated Project Team

Integrated Project Delivery. Integrated Project Delivery (IPD) is the stage of IDP that promotes collaboration between the main stakeholders involved in a project during the earliest stages of the design process. This stage is where the goals of the project are addressed and defined, allowing an exchange of information and priorities to be had between clients, designers, contractors, architects, investors, and engineers. The phases of IPD include pre-design, when data is collected and goals are determined; design, a detailed phase of schematics, development, and construction documentation needed for permissions and bidding; bidding, where appropriate contractors are selected for construction; commissioning, a process that ensures quality by on-site verification throughout design and installation; and occupancy, achieving certification of occupancy, ensuring the building is safe.[135]

Integrated Project Team. In following the Integrated Design Approach, planners, designers, technicians, builders, and stakeholders collaborate

[134] LeadingGreen, "LEED Green Associate Study Guide v4 Edition," 2017, 26.
[135] LeadingGreen, 27.

throughout the process. Typically, many contractors involved in building a house do not interact until their step of the process is needed. If problems are not identified in the design stage, they could appear later in the build, creating a higher cost to rework or in many cases, a more efficient alternative could have been used that is no longer an option. The project team involved in the Integrated Design Approach is one of the most important components of the IDP. Every discipline involved in the construction of a building should be included in the project team from the beginning. By opening access for communication and coordination between all stakeholders early in the design stage, the opportunity for error, miscommunication, and conflict diminishes.[136]

Okala Eco-design Strategy

The Okala Eco-design Strategy Wheel is an approach that overlaps with many of the same concepts involved in the Integrated Design Approach used by the Green Building Council. Okala mentions eight categories[137] to consider when approaching design, with ideas for how to achieve successful results. The Okala strategy complements the Integrated Design Approach by incorporating a structured and descriptive guideline for life cycle design, with each category containing details about how to approach each stage:

- Innovation[138]
  - Rethinking how to provide benefits
  - Designing for flexibility

[136] LeadingGreen, 28.
[137] White, Pierre, and Belletire, "Okala - the Ecodesign Strategy Wheel," 2.
[138] White, Pierre, and Belletire, 5.

  - Providing a product as a service
  - Creating a shared product
- Reduced Material Impacts[139]
  - Avoiding materials that cause damage to society or environment
  - Minimizing the quantity of materials
  - Using renewable, recycled, or reclaimed resources and materials
  - Utilization of waste products
- Manufacturing Innovation[140]
  - Minimizing waste and energy use
  - Optimizing the process for quality control
  - Designing with the intention of sustainable energy sourcing
  - Elimination of toxic emissions
- Reduced Distribution Impacts[141]
  - Reducing product weight and volume
  - Finding low impact transport options and reusable systems
  - Utilizing locally sourced materials and services
- Reduced Behavior and Use Impacts[142]
  - Designing to encourage low impact behaviors
  - Reducing energy and water consumption

[139] White, Pierre, and Belletire, 14.
[140] White, Pierre, and Belletire, 22.
[141] White, Pierre, and Belletire, 30.
[142] White, Pierre, and Belletire, 36.

- System Longevity[143]
  - Designing for durability, reuse, and easy maintenance
  - Promoting an emotional connection
- Transitional Systems[144]
  - Designing with a second life in mind
  - Allowing for the reuse of components
- Optimized End-of-Life[145]
  - Using materials that are safe for reuse or disposal
  - Designing for quick disassembly
  - Creating a business model that provides a recycling plan

Life Cycle Analysis

The Okala Eco-design Strategy would precede a life cycle analysis (LCA), a technique that helps to determine the environmental impacts of each stage of a process. An LCA begins with the raw materials and follows a product or service through processing, manufacturing, assembly, transport, product use, and end-of-life.[146] Figure 2 shows an example of the different life cycle approaches. An open-loop approach, known as cradle-to-grave, is an unsustainable system that is commonly used in building and manufacturing that does not fully consider the end-of-life stages of a product. By using a closed-loop approach, cradle-to-cradle, a more sustainable system can be

[143] White, Pierre, and Belletire, 43.
[144] White, Pierre, and Belletire, 49.
[145] White, Pierre, and Belletire, 53.
[146] LeadingGreen, "LEED Green Associate Study Guide v4 Edition," 6.

achieved where the materials at the end of a product's initial use can be recycled or reused to begin another life cycle.[147]

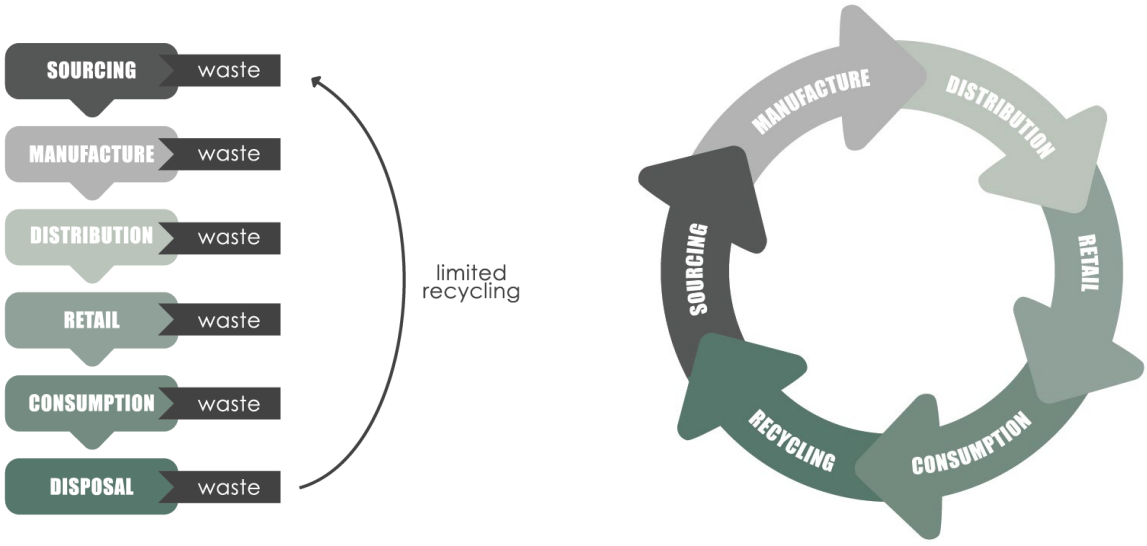

Figure 2. Life Cycle of a product or service. Left: Open-loop, cradle-to-grave. Right: Closed-loop, cradle-to-cradle.

To begin an LCA, the goal and scope of the project need to be identified. This step defines the purpose of the study, what boundaries are set, and any assumptions about expected outcomes. An inventory needs to be established in order to quantify energy usages and raw material inputs as well as any environmental releases associated with each stage of the product or service's life cycle from sourcing through end-of-life. The assessment is then conducted using inventory data to determine the impact on human health and the environment. Finally, an interpretation of the analysis is done, including the results and transparent presentation of conclusions based on the findings. Due to the lack of transparency regarding inventory for the trailers used by FEMA,

[147] LeadingGreen, 28.

this research aims to establish conceptual strategies for approaching the design of off-grid tiny housing for disaster relief and recovery, rather than performing a full life cycle analysis and comparison. Further, this research hopes to focus on gaining an understanding of the factors, such as social capital, that could influence the implementation of a possible solution.

2.6 Social Capital

Leadership and Trusted Networks

Social capital is the relationships people have with society that allow trust, norms, and networks to be formed. Rajib Shaw and Yuko Nakagawa found that communities that were able to best recover from a disaster were those that had strong social capital. Their study was done in post-earthquake Kobe, Japan and Gujarat, India – allowing an understanding of how vastly different cultures act in similar recovery environments. When assessing how disaster management was handled, Shaw and Nakagawa found that within the mitigation and response processes, social aspects were lacking.[148] In order to assess their cases fairly, they evaluated similar disasters in urban settings in developed and developing communities with relatively high damage from the events. Soni and Lohana were two of the communities observed. Both communities had democratic systems, high involvement in multidisciplinary actions, established networks outside of their own, and formal collaboration

[148] Rajib Shaw and Yuko Nakagawa, "Social Capital : A Missing Link to Disaster Recovery," *International Journal of Mass Emergencies and Disasters* 22, no. March (2004): 5.

with government; the main difference between the two communities was trust in leadership and shared thinking.[149] Trust in leadership from members of the Soni community was found to be essential in fast recovery. Despite having a lower income level, Soni recovered faster with higher satisfaction than any of the other communities observed. Lohana, despite high involvement from wealthy businesspeople trying to support rebuilding, was not as successful due to lack of trust and ability to make collective decisions.[150] This research from Shaw and Nakagawa shows that when leadership is able to gain social capital with a community, the trust that is formed and the ability of that community to be of one mind allows for a successful post-disaster recovery.

Daniel Aldrich and Michelle Meyer, like Shaw and Nakagawa, acknowledge the importance of social capital in disaster recovery. They cite several examples of neighbors acting as first responders, financial and non-financial assistance, and psychological support in times of crisis, taking note that disaster management has yet to embrace social capital as integral for recovery.[151] Their research shows that strong bonding social capital can reduce the amount of formal aid needed by a community. Aldrich and Meyer provided an example of this in post-Katrina New Orleans low-income Village de L'Est. This community was able to rebuild more efficiently than wealthier areas that suffered from less damage and flooding. Their recovery was largely due to the

[149] Shaw and Nakagawa, 16.
[150] Shaw and Nakagawa, 17.
[151] Daniel P Aldrich and Michelle A Meyer, "Social Capital and Community Resilience," *American Behavioral Scientist* 59, no. 2 (2015): 256, https://doi.org/10.1177/0002764214550299.

church's coordination with aid and its active role in ensuring any political actions were kept at bay. The trust the community had in the institution of the church, as well as the bonding ties with their friends and neighbors in the community, allowed them to successfully restore their neighborhood.[152]

Brisson and Usher show evidence that low-income neighborhoods that have received resources from outside sources (e.g. response to crisis or government funded programs) are encouraged to participate in recovery or development,[153] which can play a role in forming relationships and developing bonds that can lead the community to be more self-reliant. It is important to note that social capital is not inherent in low-income areas just as it is not necessarily inherent in more affluent areas. Social capital is determined by the ability to form trusted networks between people, organizations, and leadership within and outside of a community, which, according to Lash and Belfiore, are established by caring friends and adults, near-peers and role models, mentors and coaches, networks and weak-ties, and resources and connectors;[154] the researchers establish that these roles within a network are what define the development of social capital. Lash and Belfiore focus their research on how stresses in affording basic necessities limit success and how social capital can help to overcome those stresses.[155] More affluent neighborhoods tend to have

[152] Aldrich and Meyer, 260.
[153] Daniel S Brisson and Charles L Usher, "Bonding Social Capital in Low-Income Neighborhoods," *Source: Family Relations*, vol. 54, 2005, 646, https://www-jstor-org.ezproxy.lib.ou.edu/stable/pdf/40005268.pdf?refreqid=excelsior%3Ac12e1900d0be10ec2f487d174a01a32b.
[154] Dave Lash and Grace Belfiore, "5 Essentials in Building Social Capital," *MyWays Student Success Series - Next Generation Learning Challenge*, 2017, 2, https://s3.amazonaws.com/nglc/resource-files/MyWays_04Essentials.pdf.
[155] Lash and Belfiore, 7.

an abundancy of institutions in their community with which to become involved, while more segregated communities can suffer from limited access to these opportunities for networking.[156] These connections can lead to opportunities for growth that may not have otherwise presented themselves. This suggests that it is not the affluence of a community that determines success but the strength of connections and availability of friends, role models, mentors, networks, and resources. While more affluent areas may be able to establish these networks more easily, low-income areas can successfully come together to self-manage and adapt to stressors regardless of income, given that strong social capital is already present. This is evident in the study by Shaw and Nakagawa on post-disaster Kobe, Japan, and Gujarat, India, as well as in the successful recovery of Village De L'est in New Orleans.

While Brisson and Usher show that affluence can contribute to greater access to networking opportunities, they also note that the relationship between population density and the ability to engage in activities that build social capital is more easily found in densely populated areas;[157] John Durston's study on building social capital in rural communities, more isolated from opportunity to network, focuses on the difficulties of creating social capital where it does not exist. Durston suggests social capital is a resource that contributes to the public good, but not all transactions constitute social capital and there are formal and informal rules that define whether reciprocity

[156] Lash and Belfiore, 7.
[157] Brisson and Usher, "Bonding Social Capital in Low-Income Neighborhoods," 54:646.

contributes to social capital or not.[158] In his study, Durston states that "for the theory of social capital to have any practical usefulness to policy-makers, it must be clear that it can be built,"[159] acknowledging that this concept must be shown effective for government to be persuaded to allocate resources to this cause. In his case study in Eastern Guatemala, Durston provides some confirmation that it is possible to build social capital where it is lacking. He reviewed efforts by the International Fund for Agricultural Development and the Dutch Government for their "Proyecto de Apoyo a los Pequeños Productores de Zacapa y Chiquimula," a project in support of the small producers in Zacapa and Chiquimula, focusing on 5,000 families in 130 villages lacking in grassroots organizations or inter-family cooperation.[160] He found that the culture in this area was deeply individualistic and did not have the inherent ability to be of one mind to work toward a common goal. The people living in this area were unfamiliar with community projects and turnout to events was lacking.[161] When developing a strategy for increasing participation in community projects, the team realized that a large portion of the population had common surnames. They scaled back the efforts to organize, focusing on nuclear groups in order to form bonds in households with the same surname, promoting benefits to these smaller groups rather than the larger whole.[162]

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[158] John Durston, "BUILDING SOCIAL CAPITAL IN RURAL COMMUNITIES (Where It Doesn't Exist) Theoretical and Policy Implications of Peasant Empowerment in Chiquimula, Guatemala," 1998, 3, http://www.eclac.org.
[159] Durston, 4.
[160] Durston, 6.
[161] Durston, 6.
[162] Durston, 7.

Durston confirms the effectiveness of this strategy, stating that by the second year of activity almost every household was involved in community projects and began to actively set goals and express their needs.[163] This case study suggests that building social capital is possible through understanding the culture of an area and finding a connection among residents.

Adger et al. explore social capital further with their research of social-ecological resilience, specifically following disasters in coastal regions. The focus of their work is adaptive capacity, which is the ability to self-manage, learn, and adapt to stressors.[164] The current economic structure of coastal regions is different than it has been in the past, with more global connections and tourism influencing the vulnerability of the coasts; the researchers stress that this increased risk demands better adaptive capacity through purposeful action.[165] Adger et al. argue that prepared communities with knowledgeable residents and responsive institutions are more likely to prevent a natural phenomenon from becoming a long-term social disaster.[166] Through researching how two communities responded following separate events, the researchers found that the ability of formal and informal institutions to adapt to changing circumstances rapidly are the key to managing the long-term social impacts of natural hazards.[167]

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[163] Durston, 7.
[164] W Neil Adger et al., "Social-Ecological Resilience to Coastal Disasters," *Science* 309 (2005): 1036, https://doi.org/10.1126/science.1112122.
[165] Adger et al., 1037.
[166] Adger et al., 1038.
[167] Adger et al., 1038.

Although the changing physical environment is partly to blame for the dramatic increase of hurricane related costs over time, the researchers insist that the increased social vulnerability of coastal regions plays an equal part. They cite changes made in the Cayman Islands as an example of how adaptation through the promotion of strong social cohesion has made a distinct difference from Hurricanes Mitch and Michelle, which occurred toward the end of the last century, to Hurricane Ivan in 2004. Adger et al. conclude that large-scale changes to environment and society demand effective multilevel governance systems which promote social capital. This strength in leadership and building of a trusted network of connections is critical to implementing the necessary changes for adaptation to new norms.[168]

Brisson and Usher recognize the importance of varying levels of social capital. Bonding, what defines trusted intra-community relationships, is more personal and serves the community on a smaller scale. This allows a community to pool its resources, helping family and neighbors by using collective effort to contribute whatever is available. The researchers note that in lower-income areas, social bridging with organizations and leadership outside of a community is what can help relieve an area of the recurring need for pooling of resources by implementing long-term solutions for the root of the problem.[169] Brisson and Usher explain how social capital also has the potential to have negative influence, particularly in low-come areas that have been

[168] Adger et al., 1039.
[169] Brisson and Usher, "Bonding Social Capital in Low-Income Neighborhoods," 54:646.

systemically neglected. The formation of gangs is an example of social capital used to negatively gain power, which could lead to increased crime.[170] This suggests that extra-community bridging is necessary as a support to build trust between those living in a community and those looking in from an outside perspective.

No Place Like Home

Leanne Rivlin and Jeanne Moore recognize the importance of a holistic approach to home-making. Their 2001 study, "Home-Making: Supports and Barriers to the Process of Home," analyzes the importance of "social, physical, environmental, financial, and practical supports and barriers"[171] by finding common themes among studies on homelessness in the United States and the United Kingdom. It was found that there are many functions that go into the process of home-making that are outside of the provision of a roof and four walls. The ability to afford rent, utilities, medical expenses, and food is significant, as many people are kept in poverty due to these absolute necessities of life.

Having a sense of control over a dwelling was found to be a factor in the process of home-making. People who were provided storage and a kitchen, allowing for culture to be passed on through generations in the form of cooking,[172] proved more effective in successfully establishing a feeling of home

[170] Brisson and Usher, 54:645.
[171] Leanne G Rivlin and Jeanne Moore, "Home-Making: Supports and Barriers to the Process of Home," *Journal of Social Distress and the Homeless* 10, no. 4 (2001): 324.
[172] Rivlin and Moore, 330.

than those who were not afforded these accommodations.[173] This feeling of empowerment was also apparent in those who were given leases and keys to their apartments and the ability to decorate as they like. Familiarity of the area was found to be important in maintaining relationships and connections to family and friends, which may provide invaluable resources and emotional support that otherwise might be unavailable in an unfamiliar place. Rivlin and Moore also found that when extensive sharing is required of residents, safety became more of an issue.[174] The study touched upon the importance of having services available that support people in their journey to establish themselves. Educational services for acquiring the skills necessary to find work, health and nutrition coaching, and other skills such as cooking and budgeting could make a world of difference to people in getting them re-established into society.[175]

Charlie Kilman reinforces the findings by Rivlin and Moore in his description of the Tiny House Movement, describing the movement as one which is "rooted in a sense of individualism," explaining how making one's home his or her own is important for establishing a feeling of ownership over one's space.[176] However, he goes on to explain that despite the Tiny House Movement being largely about creating a space to feel like a home in a very customized and individual way, the Tiny House Movement actually promotes a culture change from a self-centered mindset to a community-centered mindset.

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[173] Rivlin and Moore, 331.
[174] Rivlin and Moore, 332.
[175] Rivlin and Moore, 333.
[176] Charlie Kilman, "Small House, Big Impact: The Effect of Tiny Houses on Community and Environment," *Undergraduate Journal of Humanistic Studies • Winter*, vol. 2, 2016, 7, http://tinyhousecommunity.com/faq.htm.

Being involved in a tiny house community offers more than just a house that can be tailored to suit one's needs, it offers a new culture in which people engage with each other and the natural environment in a way that is not often seen elsewhere. The freedom of having less house to pay for and maintain allows people to work less and enjoy society more, [177] creating a fuller sense of what a home can be.

Kilman acknowledges the culture shift that would need to take place for the Tiny House Movement to become mainstream. There are limitations to living tiny: the initial cost of a tiny house can be difficult to finance, as they are too inexpensive for traditional home loans and require specific classification in order to qualify for an RV loan, leaving residents to pay in cash or with unsecured personal loans; lack of privacy can be both physically and emotionally difficult; and many people often view a small home as symbolic of living in poverty.[178] While these barriers could be difficult to climb, housing subsidies could help finance tiny house loans and careful design can alleviate accessibility and privacy concerns, leaving nothing but a change in mindset standing between a tiny house and the average American. Kilman goes on to explain how it is possible to have a tiny house lifestyle without committing to such extreme square footage simply by living deliberately, as Thoreau also suggests. Living in a home that is the "right size" for one's family can reduce

[177] Kilman, 2:7.
[178] Kilman, 2:9.

cost of living, allowing better understanding of personal finances, environmental contribution, and the importance of community.[179]

2.7 Summarizing the Literature

Thoreau proposed that when the worries of affording more than the essentials are stripped away, a sense of self can begin to emerge. Impoverished people are often unable to pursue their passions because their focus is the "essential facts of life." If the essentials were provided along with educational services and support systems, it may be possible that a person could transition from once poverty stricken and victimized by a hurricane to one who is contributing unique and valuable skills to society and living a more fulfilled and healthy life. While Thoreau's intention with living in a tiny house had more to do with minimalism, self-development, and contribution to society, the research shows that there are several environmental benefits of tiny housing as well. The evaluation done by the Department of Environmental Quality in Oregon shows an overall reduction of environmental impact by reducing housing size, in addition to a recommendation of maintaining fewer possessions and avoiding wasteful material usage, supporting the practice of essentialism. Wilson and Boehland reinforce these findings by proving that even a smaller home with poor energy standards can out-perform a larger energy efficient home. By designing a tiny house using the off-grid technologies reviewed, such as passive design and a combination of RWH and NZGW reuse,

[179] Kilman, 2:9.

the environmental impact of disaster relief housing could be reduced significantly.

The government's handling of relief housing after Hurricane Katrina suffered from a lack of planning and miscommunication between agencies involved, leaving FEMA scrambling to find a solution after the storm had already done its damage. After Harvey, the same issues presented themselves. Shaw and Nakagawa found in their research that communities with strong social capital were able to recover more quickly from disaster, regardless of income level. This suggests that were federal and local governments to have better relationships with local businesses and organizations, a more seamless recovery process could take place. Aldrich and Meyer reinforce the importance of social capital, citing the recovery of Village de L'Est, a low-income neighborhood that was able to recover more effectively than wealthier areas that had suffered less damage, due to their strong internal connections with friends, neighbors, and their local church. The Make It Right Foundation's efforts to sweep in with celebrity backing was found to be ineffective despite the amount of media attention and money that was put into the project. The community of Lohana in the Shaw and Nakagawa study had the same failures, showing that despite contributions from wealthy businesspeople, recovery is not as effective without trust in leadership and strong social capital. The organization with the most successful outcome in the Lower Ninth Ward was Lowernine.org, making use of community volunteers and local connections to rebuild. Much of the literature suggests that higher levels of social capital has

positive effects on the overall wellbeing of a community, increasing economic growth, health, and effectiveness of leadership. In the following chapter of this research, a sustainability framework is used to determine whether the estimated calculations for an off-grid tiny house and strategies for “closing the gap” between the provision of relief housing and implementation of solutions could create an effective system for long-term recovery.

CHAPTER 3: METHODOLOGY

3.1 Research Overview

Relief housing continues to be one of the most complex aspects of disaster response due to the various challenges presented to society, the environment, and the economy. Solutions have been proposed by countless interdisciplinary teams using several techniques to address these challenges. This research uses the currently available literature to review the most effective techniques for providing efficient, affordable relief housing and support to displaced hurricane victims, and determine if there is a more sustainable solution for disaster relief housing than the trailers that have been used in the past and what can be done to implement the solutions that are found.

Due to the lack of transparency regarding expenditures, this research compares the handling of the situation between Hurricanes Katrina and Harvey rather than the exact unit costs and environmental impact from one storm to the other. The figures used to determine the past expenses are estimates based on available reports from the events that transpired post-disaster regarding housing for displaced victims in Hurricane Katrina and Hurricane Harvey. The average costs of tiny housing and systems for off-grid function are based on a review of projects from several builders, both do-it-yourself and professional. It is noted that some technologies are not found to be currently available for residential or small-scale use and costs for these systems are estimated.

3.2 Research Method

Sustainability Framework

Evaluating the various technologies and findings that have been reviewed in this literature by using a framework such as the one established by Arc Eziyi O. Ibem and Egidario B. Aduwo for understanding sustainable housing could help to determine whether a system is truly sustainable. Their research reflects upon the importance of housing, acknowledging it as an integral part of sustainable development due to its role in such areas as economic development, employment, environmental impact, energy expenditure, and preparedness for natural disasters.[180]

The framework Ibem and Aduwo developed is mapped in Figure 3:

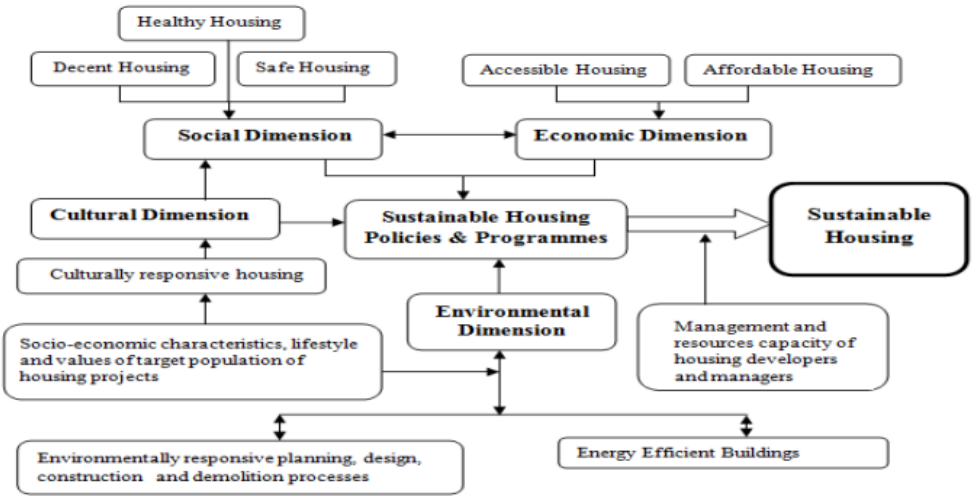

Figure 3. The Framework for understanding Sustainable Housing. Ibem and Aduwo, A Framework for Understanding Sustainable Housing for Policy Development and Practical Actions, 2015, prepared for Architects Registration Council of Nigeria 6.[181]

[180] Arc Eziyi O Ibem and Egidario B Aduwo, "A FRAMEWORK FOR UNDERSTANDING SUSTAINABLE HOUSING FOR POLICY DEVELOPMENT AND PRACTICAL ACTIONS," *Architects Registration Council of Nigeria*, 2015, 3, https://doi.org/10.1002/9781119196563.ch1.

[181] Ibem and Aduwo, 6.

The four dimensions Ibem and Aduwo define in their framework are as follows:

Economic. The two key elements highlighted for the economic dimension are accessibility and affordability. Accessibility focuses on providing housing regardless of income class, age, gender, or education, ensuring the fair treatment of people from all backgrounds.[182] The affordability of housing refers to ensuring the cost of housing does not put undue pressure on household income, leaving residents unable to afford the basic essentials of life.[183]

Environmental. The current focus in this dimension is energy efficiency, sustainably sourced building materials, reduction of waste, and water systems. This section mentions the utilization of passive energy saving techniques such as building orientation, façade colors and textures, ventilation, and insulation as well as renewable energy generation and improving the efficiency of all utilities including water, for minimizing impact.[184]

Social. The social dimension involves healthy, decent, and safe housing, which are all important aspects for maintaining a high quality of life. Healthy housing includes maintaining air quality, protection against disease, and preventing threats to structural stability and other factors that could bring about physical harm.[185] They also mention the importance of building social capital by forming partnerships between government and the local community

[182] Ibem and Aduwo, 12.
[183] Ibem and Aduwo, 13.
[184] Ibem and Aduwo, 14–15.
[185] Ibem and Aduwo, 9.

and promoting the use of local services and materials for housing projects.[186] Decent housing includes modern accommodations (eg. kitchen, bathroom), a structurally sound building, and reasonable insulation which provides thermal regulation.[187] Safety refers to protection from both natural and human threats to the residents and their space.[188]

Cultural. Sustainability typically focuses on the three core pillars of economy, environment, and society; Ibem and Aduwo have added a fourth dimension, highlighting the importance of culture and what role it plays in sustainable development. The researchers argue that culture dictates lifestyle, values, traditions, and behaviors and that these things should be considered separately from the social dimension,[189] which focuses on safety and health.

This framework was chosen because of its intentional separation of culture from the social dimension. Ibem and Aduwo mention that with an integrated approach to sustainable housing, accessibility opens up to people of every income class, addressing diverse needs determined by background, lifestyle, and fundamental values.[190] As Rivlin and Moore found in their study, allowing culture to be passed on through generations was an important factor in successful reintegration into society after being homeless. It is also important to understand culture for assessing populations to help determine key actions that can contribute to building social capital, as was shown in the

[186] Ibem and Aduwo, 13–14.
[187] Ibem and Aduwo, 7.
[188] Ibem and Aduwo, 8–9.
[189] Ibem and Aduwo, 11.
[190] Ibem and Aduwo, 4.

case study in Eastern Guatemala by John Durston. Ibem and Aduwo regard each aspect of their framework important, noting that to achieve truly sustainable housing, the criteria of all four dimensions must be met. This research seeks to use this framework as a tool to help determine whether the environmental, economic, social, and cultural dimensions have been met in order to achieve a sustainable system for housing those displaced after a hurricane.

Economic Dimension

Unit price. Information about unit prices and size for individual FEMA trailers is retrieved from various sources including Congressional reports, research done by the US Government Accountability Office, and news outlets. Costs per unit were found to range between US$18,531.35 to $229,000, in 2005 dollars. The lowest amount found adjusted for inflation is US$24,161.68.[191]

The price of an individual tiny house is calculated by averaging the cost of 10 randomly selected projects. As shown in Figure 4, this research found the average price of a 240 square foot (22.3 square meter) tiny house to be US$14,023.02, with the cost per square foot amounting to US$58.43.

The builders and their projects are listed below:

- MiniMotives by Macy Miller[192]

[191] Mccarthy, "FEMA Disaster Housing and Hurricane Katrina: Overview, Analysis, and Congressional Issues Analyst, Emergency Management Policy Government and Finance Division," 14.
[192] Macy Miller, "Budget," MiniMotives, 2011, http://minimotives.com/budget/.

- MotivatedMontanan[193]
- Half-Tree House by JacobsChang[194]
- Springtown, Texas Tiny House[195]
- Dual Lofts in Baton Rouge, Louisiana[196]
- Tiny Maison by Sicily Kolbeck[197] [198]
- Berzin Tiny House[199]
- Apis Cor[200]
- Soleil by Erin and Dondi[201]
- The Big Tiny by Dee Williams[202]

[193] "Quick Facts," Motivated Montanan, accessed March 7, 2019, https://motivatedmontanan.weebly.com/quick-facts.html; "Budgeting Resources," Motivated Montanan, accessed March 7, 2019, https://motivatedmontanan.weebly.com/budgeting-resources.html.
[194] James Brillon, "Cabin by JacobsChang Is Set among Trees in Upstate New York," Dezeen, 2017, https://www.dezeen.com/2017/07/08/cabin-jacobschang-treehouse-upstate-new-york-architecture-residential-woodland-usa/.
[195] "Springtown Tiny House," Tiny Home Builders, accessed March 15, 2019, https://www.tinyhomebuilders.com/tiny-house-marketplace/tiny-house-for-sale-.
[196] Alex, "27-Foot Modern Tiny House with Dual Lofts for $22k," Tiny House Talk, 2018, https://tinyhousetalk.com/27-foot-modern-tiny-house-with-dual-lofts-for-22k/.
[197] "La Petite Maison," Tiny Maison, 2014, http://tinymaison.blogspot.com/.
[198] TED Staff, "A Recap of Session 2 of TEDYouth 2014," TED Blog, 2014, https://blog.ted.com/a-recap-of-session-2-of-tedyouth-2014/.
[199] Kuldeep Chauhan, "Berzins Family's 168 Sq Ft DIY Tiny House Costs Just $12,000," Home Harmonizing, accessed March 11, 2019, http://homeharmonizing.com/berzins-familys-heroic-reaction-to-2008s-recession-a-168-sq-ft-diy-tiny-house/.
[200] Leanna Garfield, "Apis Cor Invented a $10,000 House That Can Be Built in One Day," Business Insider, 2017, https://www.businessinsider.com/house-built-one-day-apis-cor-2017-3.
[201] "DIY Tiny Home Under $9000," Tiny Homes Map, accessed March 11, 2019, http://www.tinyhomesmap.com/diy-tiny-home-under-9000-10-hq-pictures/; Erin and Dondi, "Erin and Dondi | Our Travels, Exploits, and Adventures," 2014, https://erinanddondi.wordpress.com/.
[202] Carol Estes, "Living Large in a Tiny House," Yes Magazine, 2008, https://www.yesmagazine.org/issues/sustainable-happiness/living-large-in-a-tiny-house.

BUILDER	SIZE	COST OF BUILD
MiniMotives	196	11,416.16
MotivatedMontanan	144	10,975.39
Half-Tree House	360	20,000.00
Springtown	448	25,000.00
Dual Lofts	270	22,000.00
Tiny Maison	128	9,838.69
Berzin Tiny House	168	12,000.00
Apis Cor	409	10,000.00
Soleil	200	9,000.00
The Big Tiny	84	10,000.00
	240	14,023.02

Figure 4. Average cost and size of a tiny house.

Energy. According to the summary for annual household consumption by the Energy Information Administration for 2015, the monthly utility bill for a 240 square foot (22.3 square meter) mobile home is an average of US$29.20.[203] It is reasonable to assume a trailer of this size would cost approximately the same amount due to similar insulation and use.

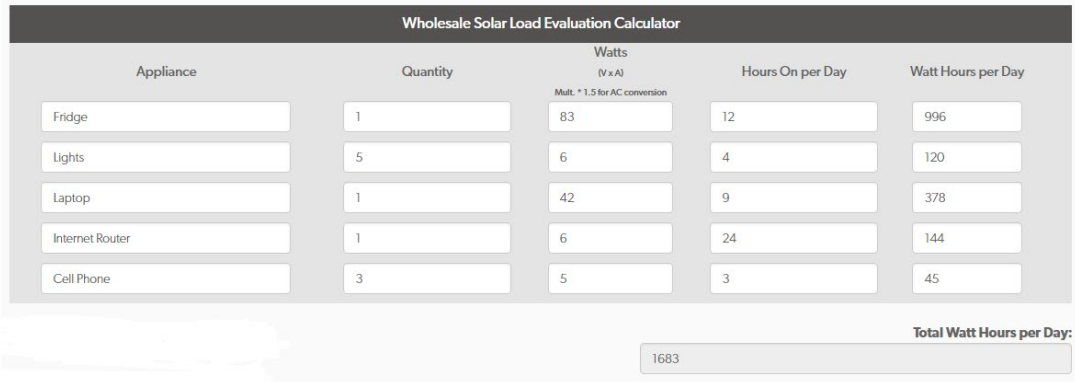

Figure 5. Load calculator. Wholesale Solar, *Load Calculator.*204

[203] US Energy Information Administration, "Summary Annual Household Site Consumption and Expenditures in the US - Totals and Intensities, 2015," 2015, 2, https://www.eia.gov/consumption/residential/data/2015/c&e/pdf/ce1.1.pdf.
[204] "Off-Grid Solar System Calculator," Whole Sale Solar, accessed March 5, 2019, https://www.wholesalesolar.com/solar-information/start-here/offgrid-calculator#load-evaluation.

Planning for off-grid energy usage requires the calculation of how many kilowatt-hours per day would be needed. Using a load calculator, as shown in Figure 5, it was found that as little as 1,683 watt-hours per day can provide a comfortable life with access to amenities such as internet, kitchen appliances, and morning routine essentials while relying entirely on a small photovoltaic (PV) system used in conjunction with passive design techniques for heating and cooling.[205] [206]

PV panels can provide electricity for lighting and appliances, eliminating the need for grid connection. In 2010, residential PV system cost was around US$7.24 per watt, according to a report by the National Renewable Energy Laboratory.[207] The price of PV systems has dropped significantly due to greater demand in the market, averaging US$1.11 per watt in 2017 for a one-axis-tracking-utility-scale system,[208] making a 1,683 watt system cost US$1,868.13. Relying on electricity from solar power requires a battery backup to store for use at night or days with cloud cover. Given that most US hurricanes impact coastal cities in the Gulf of Mexico or southern Atlantic[209] where sunlight is abundant, a tiny house for use in this scenario would require a much smaller battery than would one in the north where cloud cover is of

[205] "Load Calculators," altE Store, accessed March 5, 2019, https://www.altestore.com/store/calculators/load_calculator/.
[206] Amy Beaudet, "Solar Panels for a Tiny House," altE Store, 2017, https://www.altestore.com/blog/2017/05/solar-panels-tiny-house/#.XA-5iOhKhhE.
[207] Ran Fu et al., "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017," 2009, vi, www.nrel.gov/publications.
[208] Fu et al., iv.
[209] Eric S Blake et al., "NOAA Technical Memorandum NWS NHC-6 THE DEADLIEST, COSTLIEST, AND MOST INTENSE UNITED STATES TROPICAL CYCLONES FROM 1851 TO 2010 (AND OTHER FREQUENTLY REQUESTED HURRICANE FACTS)," 2011, 30, https://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf.

more concern (and the use of a backup generator may be necessary). New Orleans has an average of 57% possible sunshine,[210] experiencing 101 clear days, 118 partly cloudy days, and 146 cloudy days for an average of 219 days with sun.[211] Daylight hours vary throughout the year, though the city experiences an average of 12 hours and eight minutes daily. The longest day is June 21 with 14 hours and five minutes of daylight, while December 21 is the shortest day with 10 hours and 13 minutes.[212] A single gel cell battery should provide enough of a backup for a 2 kilowatt-hour system that would cost approximately US$583.[213] The total initial cost of off-grid energy would be approximately US$2,451.13.

Water retrieval. A monthly water bill for the average New Orleans[214] family of three is estimated to be US$24.11, assuming 23.3 gallons (88.2 liters) of water usage from daily activities per person, which are defined in this methodology. Although the cost of a residential net-zero greywater reuse system is unable to be attained, the Orbital Systems closed-loop shower, which uses the same technology that would be needed to treat and reuse water in a

[210] National Oceanic and Atmospheric Administration, "RANKING OF CITIES BASED ON % ANNUAL POSSIBLE SUNSHINE IN DESCENDING ORDER FROM MOST TO LEAST AVERAGE POSSIBLE SUNSHINE," 2004, https://www1.ncdc.noaa.gov/pub/data/ccd-data/pctposrank.txt.
[211] National Oceanic and Atmospheric Administration, "Cloudiness - Mean Number of Days," accessed March 6, 2019, https://www1.ncdc.noaa.gov/pub/data/ccd-data/clpcdy15.dat.
[212] "Average Weather in New Orleans," WeatherSpark, accessed March 6, 2019, https://weatherspark.com/y/11799/Average-Weather-in-New-Orleans-Louisiana-United-States-Year-Round.
[213] pad tiny houses, "How to Power Your Tiny House With Solar Power," 2017, https://padtinyhouses.com/power-your-tiny-house-with-solar/.
[214] Bureau of Governmental Research, "The Proposed S&WB Rate Increases in Perspective," 2012, 3, https://www.bgr.org/wp-content/uploads/2017/07/BGR_SWB-rate-proposal-.pdf.

tiny house, was found to cost approximately US$5,900.[215] From this available information, it is assumed that a NZGW reuse system would be able to be designed at this price point. There are no monthly expenses associated with a greywater recycling system apart from occasional maintenance such as filters, which are not included in this estimate.

Environmental Dimension

Energy consumption. Using the basic carbon footprint calculator provided by the Environmental Protection Agency, it was found that a small household in the Lower Ninth Ward in New Orleans spending US$29.20 on electricity produces an estimated 3,049 lbs (1.4 metric tons) of CO_2 annually.[216] It is agreed that the average tiny house produces an estimated 2,000 lbs (0.9 metric tons) of CO_2 annually: 1,144 lbs (0.52 metric tons) from electricity, 558 lbs (0.25 metric tons) from heating, and 286 lbs (0.13 metric tons) from cooling.[217] [218] [219] However, using off-grid and passive technologies, carbon emissions generated by energy demand can be negated entirely.

Water consumption. The recommended water intake according to WebMD is between half of one ounce and one ounce per each pound of body

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[215] Linda Braden, "The Future of Shower Technology," Angie's List, 2016, https://www.angieslist.com/articles/future-shower-technology.htm.
[216] US Environmental Protection Agency, "Carbon Footprint Calculator," accessed March 8, 2019, https://www3.epa.gov/carbon-footprint-calculator/.
[217] A Thompson, "Tiny Houses the Answer to Our Environmental Problems?," GoGreen.org, 2017, http://www.gogreen.org/blog/tiny-houses-the-answer-to-our-environmental.
[218] James Hardie Building Products, "Sustainable and Small: The Tiny House Movement" (American Institute of Architects, 2017), https://www.aia.org/articles/141631-sustainable-and-small-the-tiny-house-moveme:36.
[219] Daphne Stanford, "Tiny Houses Have Even Tinier Carbon Footprints," Renewable Energy World, 2015, https://www.renewableenergyworld.com/ugc/articles/2015/12/tiny-houses-have-even-tinier-carbon-footprints.html.

weight. According to the CDC, an average male living in the US weighs approximately 195.7 lbs (88.8 kilograms) and would need between 97.5 and 195.7 ounces (2.9-5.8 liters) of water, an average of 146.6 ounces (4.3 liters) per day. An average female living in the US weighs approximately 168.5 lbs (76.4 kilograms) and would need between 84.3 and 168.5 ounces (2.5-5 liters) of water, an average of 126.4 ounces (3.7 liters) per day. The average amount of water needed per person per day is 136.5 ounces, or just over one gallon (3.8 liters). The average American takes an 8.2-minute shower, using 17.2 gallons (65.1 liters) of water at a flow of 2.1 gallons (7.9 liters) per minute.[220] Using a 1.5 gallon (5.7 liter) per minute showerhead can reduce this amount to 12.3 gallons (46.6 liters) per day. According to Olivia Rose-Innes, an EnviroHealth expert, general hygiene activities such as brushing one's teeth and washing one's hands use an average of 8.1 gallons (30.8 liters) per week, calculated to be 1.2 gallons (4.5 liters) per day. She also found the average amount of water used in hand-washing dishes to be 16.6 gallons (63 liters) per week or 2.4 gallons (9 liters) per day.[221] This research assumes the resident visits a laundromat to wash clothing. The most significant difference in water usage between a trailer on a grid connection and an off-grid tiny home is the gallons used to flush a toilet. This research assumes the off-grid tiny home will use a composting toilet, where the grid-connected trailer uses a standard toilet that

[220] "Showers | Home Water Works," Home Water Works, accessed March 7, 2019, https://www.home-water-works.org/indoor-use/showers.
[221] Olivia Rose-Innes, "How Much Water Do You Use per Day?," Health24, 2018, https://www.health24.com/Lifestyle/Environmental-health/see-how-much-water-do-you-use-per-day-20170613.

consumes an average of 6.4 gallons (24.2 liters) assuming five flushes per day using a low-flow 1.3 gallon (4.9 liter) per flush toilet.[222] This brings the total daily water consumption per person for a trailer to 23.3 gallons (88.2 liters).

Determining the amount of water necessary to sustain a household is critical to the viability of an off-grid home. The average water consumption of an adult living in a tiny house varies, though it can be estimated to be 16.9 gallons (64 liters) per adult per day while living comfortably, as shown in Figure 6. Over the course of a year, a single adult would use approximately 6,168.5 gallons (23,350.3 liters) of water.

WATER CONSUMING ACTIVITY	GALLONS/DAY
drinking	1.0
1.5 GPM shower head	12.3
general hygiene	1.2
hand-washing dishes/full sink	2.4
	16.9

Figure 6. Average water usage in an off-grid tiny house.

Social Dimension

Formaldehyde exposure. As of 2012, the CDC, among other health organizations such as the World Health Organization, recognize 40 parts per billion (ppb) to be a level at which formaldehyde can cause acute symptoms such as nose bleeds, headaches, and dizziness in sensitive individuals, particularly children or the elderly. Intermediate levels of exposure can occur at

[222] "How Many Gallons of Water Does It Take to Flush a Toilet?," Home Guides, accessed March 8, 2019, https://homeguides.sfgate.com/many-gallons-water-flush-toilet-88812.html.

30 ppb, while chronic conditions can occur at levels as low as eight ppb. This suggests that no level above eight ppb of formaldehyde exposure is safe for an extended duration.[223] In 2006, Gulf Stream conducted testing for the carcinogen on a sampling of their occupied and unoccupied trailers. Despite knowledge of toxic levels of formaldehyde found in those inspections, the company kept quiet on this matter. It was later discovered that their results revealed CH_2O levels over 100 ppb in every trailer tested, with some trailers testing as high as 4,000 ppb.[224]

Indoor environment. A field test done on the units by Yan Wang et al. showed indoor air temperature was consistently higher than outdoor temperature, showing a maximum difference of 27 degrees Fahrenheit (15 degrees Celsius), compared to a 16.2-degree Fahrenheit (9-degree Celsius) difference when allowing airflow via open windows and doors.[225] The same study provided a questionnaire for victims, asking them to rate their sleep quality and mental state. The results of the 300 returned surveys showed 50% experiencing lower sleep quality after moving into the prefabricated relief housing possibly contributing to a worsening mental state, something that was reported in over 80% of victims' responses.[226] Additionally, the study shows

[223] Marilyn Black, "A Formaldehyde Update" (WHO Children's Health Committee, 2012), https://ulchemicalsafety.org/wp-content/uploads/2017/06/Doc-1-A-Formaldehyde-Update-Prepared-for-WHO.pdf.
[224] US Congress, House of Representatives, Committee on Oversight and Government Reform. "Manufacturers of FEMA Trailers and Elevated Formaldehyde Levels." 110th Cong., 2nd sess., 2008.
[225] Yan Wang et al., "The Influence of the Deteriorations in Living Environments on the Health of Disaster Victims Following a Natural Disaster," *Procedia Engineering* 121 (2015): 206, https://doi.org/10.1016/j.proeng.2015.08.1054.
[226] Wang et al., 208.

that 58.6% of victims noted a loss of body weight. Increase in body temperature has been demonstrated to suppress appetite;[227] consequently, the researchers concluded that victim weight loss was due to the indoor air temperature leading to a loss of appetite, which was reported in 54.5% of victims.[228] Sickness was also reported to have increased. The study shows that 44.4% of disaster victims visited their doctors more often after moving into relief housing due to cold, fever, heatstroke, diarrhea, and dyspepsia.[229]

Social capital. Through networking and building trust between local residents, businesses, organizations, and governments, strong social capital can be established. According to Shaw and Nakagawa, this connection provides a pivotal role in disaster recovery, demonstrating in their study that communities with strong social capital are able to recover faster and more effectively, regardless of income. The literature is reviewed to gain an understanding of the ways in which healthy, decent, and safe housing can be established. Further, it is determined whether social capital can assist with the implementation of a lasting solution for housing victims after a hurricane.

Cultural Dimension

Interpreting the cultural dimension of the sustainable housing framework, home-making is considered as a potential key factor to provide for

[227] Kevin Litman-Navarro, "Brain 'Heat Switch' Reveals Why You're Not Hungry After an Intense Workout: Suppressing Your Appetite May Boil down to Body Heat.," Inverse, 2018, https://www.inverse.com/article/44155-brain-heat-switch-kills-hunger-pangs.
[228] Wang et al., "The Influence of the Deteriorations in Living Environments on the Health of Disaster Victims Following a Natural Disaster," 209.
[229] Wang et al., 210.

more than the basic necessities of life. Services such as job training and access to gathering places are also considered as important factors for developing a resilient system. The Lower Ninth Ward and Kashmere Gardens were two of the neighborhoods reviewed to gain an understanding of the background and social connections in the areas impacted most from Hurricanes Katrina and Harvey. It is noted how nurturing the cultural necessities of affected communities could improve post-hurricane recovery.

The following analysis provides a critical evaluation of design strategies to determine if they could contribute to a more resilient system. By assessing the studies and technologies reviewed in the literature and applying them to the framework provided by Ibem and Aduwo, an understanding of sustainable housing can be gained. This understanding of the dimensions, processes, and technologies that go into creating sustainable housing can assist in answering whether there is a more sustainable solution for disaster relief housing than the trailers that have been used in the past. Once an answer to that question is able to be established, the implementation of the solution can be discussed.

CHAPTER 4: ANALYSIS

4.1 Financial Costs of Relief Housing

Unit Cost

The GAO provided a report in 2007 concerning the cost of a selection of individual FEMA trailers at group sites used in Mississippi. The unit price at the Port of Bienville Park, one of the group sites researched, included a breakdown of the expense for individual trailers, transport and installation, construction, and maintenance; with the added cost of these services, the figures were well into six digits per trailer, amounting to as much as US$229,000,[230] which could afford a three bedroom, 1,400 square foot (130 square meter) house in New Orleans in 2018.[231] The expense for supplying trailers was unquestionably higher than using existing rental housing, and in many cases, the repairs made to victims' residences would have been cheaper than keeping the victims in trailers.[232] The GAO report found that FEMA was spending up to US$72,000 annually on maintenance fees alone per each of the eight trailers sited at Bienville Park because of mismanaged group-siting.[233] Group sites such as Bienville Park operate with fixed rates regardless of the

[230] US Government Accountability Office, "Ineffective FEMA Oversight of Housing Maintenance Contracts in Mississippi Resulted in Millions of Dollars of Waste and Potential Fraud," 2007, 5, https://www.gao.gov/new.items/d08106.pdf.
[231] Zillow.com, "New Orleans Real Estate - New Orleans LA Homes For Sale," 2018, https://www.zillow.com/homes/for_sale/New-Orleans-LA/house_type/19594_rid/220000-229000_price/918-955_mp/globalrelevanceex_sort/30.422624,-89.407425,29.653449,-90.357743_rect/9_zm/0_mmm/.
[232] US Government Accountability Office, "Disaster Housing: FEMA Needs More Detailed Guidance and Performance Measures to Help Ensure Effective Assistance after Major Disasters," 2009, https://www.gao.gov/new.items/d09796.pdf.
[233] US Government Accountability Office, "Ineffective FEMA Oversight of Housing Maintenance Contracts in Mississippi Resulted in Millions of Dollars of Waste and Potential Fraud," 6.

number of units placed; with better management of the operation, this expense could have been reduced drastically. The report found that FEMA spent US$4.4 million for utilities at some of these group sites.[234] It was found that a contractor at a commercial site charged FEMA US$245 for septic service to be performed every other day on 61 trailers. The report acknowledges that the agency "could have saved US$1.5 million by reassigning the septic cleaning services to a cheaper company, but it did not exercise this option."[235] The case studies referenced are from research done on contracts in Mississippi, however, it is noted in the report that similar contracts were awarded in Louisiana.[236]

According to Katherine Browne, author of "Standing in the Need: Culture, Comfort, and Coming Home After Katrina," the initial wave of 240 square foot (22.3 square meter) trailers used across the affected states cost an average of US$75,000.[237] After the formaldehyde issue created demand for action, new trailers were issued by FEMA and tested to meet safety standards; these models were reported to have cost between US$45,000 and $75,000 per trailer.[238] The amount spent on relief housing post-Katrina is not agreed upon, though several sources report average unit price to be approximately

[234] US Government Accountability Office, 2.
[235] US Government Accountability Office, 6.
[236] US Government Accountability Office, "Ineffective FEMA Oversight of Housing Maintenance Contracts in Mississippi Resulted in Millions of Dollars of Waste and Potential Fraud," 2007, 10, https://www.gao.gov/new.items/d08106.pdf.
[237] Katherine E Browne, *Standing in the Need: Culture, Comfort, and Coming Home After Katrina* (University of Texas Press, 2015), 79.
[238] The Associated Press, "FEMA Rolls out New Disaster Mobile Homes," NBC News, 2009, http://www.nbcnews.com/id/30745820/ns/us_news-life/t/fema-rolls-out-new-mobile-homes-disasters/#.XH1IW4hKhhE.

US$75,000. In addition to disagreements about cost per unit, similar disagreements are had about the number of units provided.

Representative Jeff Flake in a 2005 C-Span interview in response to issues brought about by Hurricane Katrina, stated FEMA had already spent US$3.3 billion to buy and manufacture housing for victims.[239] Further, in a statement given by Deputy Inspector General for Disaster Assistance Oversight, Matt Jadacki, before the House of Representatives in 2007, it was noted that FEMA purchased 143,000 travel trailers in response to Hurricane Katrina,[240] no amount was given in his statement for the cost of the units. A report for Congress prepared at the same time in 2007 by the Congressional Research Service states that FEMA purchased 145,699 units at a cost of US$2.7 billion (the adjusted amount for inflation to 2018 dollars is US$24,161.68 per trailer).[241] It is unclear how much was actually spent on the units provided to storm victims or exactly how many trailers were requested from FEMA after Katrina. Ease of access and transparency of the unit price for models of trailers used by the agency has not improved since 2005; the new trailers used post-Harvey in 2017 were reported to have cost US$40,000 each,[242] though this number is unable to be verified. The cost-breakdown for maintenance and installation for the units used in Houston is not available at this time.

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[239] C-Span, "Hurricane Katrina Federal Spending," 2005, https://www.c-span.org/video/?188824-7/hurricane-katrina-federal-spending.
[240] Matt Jadacki, "Statement of Matt Jadacki Deputy Inspector General for Disaster Assistance Oversight," (2007), 3, https://www.oig.dhs.gov/sites/default/files/assets/TM/OIGtm_MJ_022807.pdf.
[241] Mccarthy, "FEMA Disaster Housing and Hurricane Katrina: Overview, Analysis, and Congressional Issues Analyst, Emergency Management Policy Government and Finance Division," 14.
[242] Michael Sisak and Emily Schmall, "FEMA Trailers Auctioned at Fire Sale Prices Prior to Harvey Landfall," Claims Journal, 2017, https://www.claimsjournal.com/news/southcentral/2017/09/18/280605.htm.

Going Tiny

While tiny houses carry a stigma of being an unaffordable, bourgeois housing alternative for privileged upper-middle-class people, this is far from reality. Tiny houses come in several pricing ranges; the do-it-yourself option can be done for approximately US$15,000; a custom builder using high-quality materials will charge between US$50,000 and $75,000 using a base model, while the more extravagant, custom built homes can cost over US$80,000.[243] RVs and travel trailers, depending on class, have a median cost between US$40,000 and $100,000.[244] These figures show that tiny houses are not only affordable, but they offer competitive pricing with other small housing options while maintaining the high quality of a conventional home that trailers often lack.

It is argued that tiny housing costs more per square foot than a conventional home. Macy Miller of *MiniMotives* acknowledges that when comparing price per square foot, the expense is higher, but she suggests that the value is not being evaluated fairly and that the tiny house is performing the same functions as the conventional house at one third the price. As mentioned, the example tiny house is an assumed direct comparison to a conventional home, which is not typical of most tiny houses. Many tiny house owners choose to design and construct their own homes, resulting in a much more

[243] pad tiny houses, "How Much Does a Tiny House Cost? DIY Building vs Buying from a Builder," 2017, https://padtinyhouses.com/how-much-does-a-tiny-house-cost/.
[244] Roverpass, "RV Cost: What RV Prices Can I Expect When I Buy?," 2016, https://www.roverpass.com/blog/cost-of-buying-an-rv/.

cost-effective build than would using a professional service. Though some tiny house builders are architects, engineers, or have a background in construction, many are inexperienced and have managed to create effective, inexpensive, and aesthetically pleasing homes.

The cost of building a 240 square foot (22.3 square meter) tiny home was found to be an average of US$14,023.02 based on a random selection of 10 tiny houses. Cost of building ranged from approximately US$9,000 to $25,000, depending on availability of materials and builder experience. It is worth noting that the Tiny Maison project was built by a 13 year-old and her mother as part of an alternative learning, project-based school.[245] This encourages the theory that a multi-disciplinary team tasked with designing a structure specifically for disaster relief housing could accomplish the feat.

4.2 Environmental Impact

Energy Usage

In some locations, unoccupied FEMA trailers had been left with lights on for security and air conditioning running for circulation to prevent toxic build-up of chemicals used in the materials from which they were constructed;[246] this lack of conservation further perpetuates the problem with energy waste. Using a combination of passive and active technologies through intelligent design as suggested by Carlos Ochoa and Isaac Capeluto, housing has the

[245] "La Petite Maison."
[246] Katie Atkins, "14 FEMA Trailers in Keys Have AC Running but Remain Empty" (Miami Herald, 2018), https://www.miamiherald.com/news/local/community/florida-keys/article197563464.html.

potential to make the most out of the energy it can harness. Further, a major bottleneck to getting victims into temporary housing after Hurricane Harvey was locating venues with utility hookup, performing the service, and providing the necessary inspection required prior to operation and use. Careful planning and design of off-grid housing could have eliminated the need for scheduled field technicians to locate hookup points and provide service to ensure units had working electricity. The greater energy demand in trailers, especially when in continuous active use, increases environmental footprint, something that the Tiny House Movement actively seeks to reduce by focusing heavily on efficiency, ensuring homes will be sustainable long-term and throughout the changing seasons.[247] While the emissions from an average, grid-connected tiny home are low when compared to a trailer, a tiny house with net-zero emissions is possible by using energy efficient appliances and lighting, solar panels, clever usage of space, high-quality insulation, and passive design techniques when building.[248]

Water and Waste Management

There is often limited access to clean water and other utilities after storms, but using different techniques for harnessing heat, electricity, and water, locations without utility hookup capabilities become an option for placement of relief housing. Hurricanes form over warm ocean water near the

[247] LLC Constellation Energy Resources, "Energy Secrets of the Tiny House Movement," 2017, https://blog.constellation.com/2017/08/21/what-is-tiny-house-living/.
[248] Ashley Ozery, "Tiny Homes Are Big On Energy Efficiency" (Alliance to Save Energy, 2015), https://www.ase.org/blog/tiny-homes-are-big-energy-efficiency.

equator,[249] making most regions affected by these types of storms those which are humid and tropical or subtropical. Humid, subtropical climates produce an average of 100 inches (254 centimeters) of coastal rainfall per annum and 25 inches (63.5 centimeters) of inland rainfall.[250] A 240 square foot (22.3 square meter) tiny house with a roof pitched at 4/12 is approximately 253 square feet (23.5 square meters),[251] with the potential to yield 150 gallons (567.8 liters) of water per inch of rain. A RWH system on the example tiny house in a humid, subtropical climate such as New Orleans, a location receiving an average annual rainfall of 63.5 inches (161.29 centimeters),[252] would produce approximately 9,525 gallons (36,056 liters) per year. With the addition of 280 square feet (26 square meter) of retractable awning designed to collect rainwater, an additional 11,112.5 gallons (42,065.4 liters) of water can be harvested, bringing the total yield to 20,637.5 gallons (78,121.4 liters) per year. Based on the calculations above, RWH alone could supply water for a household containing up to three adults.

A hybrid system that utilizes a combination of rainwater harvesting and greywater reuse as proposed by Leong et al. could further reduce the amount of water needed to supply a household, making disconnection from municipal

[249] National Aeronautics and Space Administration, "How Do Hurricanes Form?," accessed January 27, 2019, https://pmm.nasa.gov/education/articles/how-do-hurricanes-form.
[250] Michael E. Ritter, "The Physical Environment: An Introduction to Physical Geography," 2006, http://www.earthonlinemedia.com/ebooks/tpe_3e/title_page.html.
[251] Calculator.net, "Roofing Calculator," accessed January 27, 2019, https://www.calculator.net/roofing-calculator.html?acarea=250&acareaunit=foot&roofpitch=4&tp=ar&x=42&y=15.
[252] US Climate Data, "Climate New Orleans - Louisiana and Weather Averages New Orleans 1961-1990 Normals," 2018, accessed October 21, 2018, https://www.usclimatedata.com/climate/new-orleans/louisiana/united-states/usla0338.

water even more viable of a solution as such a large catchment area would not be needed for harvesting potable water. With the inclusion of a NZGW reuse system in the design of a self-sustaining home, energy requirements could be drastically reduced, particularly when heating water. As mentioned in the research done by Gassie and Englehardt on the topic, greywater retains an estimated 3.6% of total thermal energy demand by people living in the United States, allowing water to return to the tap warm, requiring minimal energy to reheat.[253] Additionally, a NZGW reuse system is particularly effective in combination with a dry toilet.[254] A dry toilet allows water imports and exports to be eliminated completely as blackwater would not be generated. It is noted that pharmaceutical and pesticide presence should be addressed[255] in designing a system, particularly when attempting to meet potable water standards.

Materials

Travel trailers use a high number of formaldehyde-containing materials such as pressed wood products in order to keep the cost of construction and the weight of the unit down. Pressed wood products such as particle board, plywood, and medium-density fiberboard are bound together with resins containing high amounts of CH_2O.[256] Using reclaimed, locally-sourced solid

[253] Gassie and Englehardt, "Advanced Oxidation and Disinfection Processes for Onsite Net-Zero Greywater Reuse: A Review," 385.
[254] Gassie and Englehardt, 385.
[255] Gassie and Englehardt, 386.
[256] Australian Government Department of Health, "Formaldehyde in Pressed Wood Products," 2016, https://www.nicnas.gov.au/chemical-information/factsheets/chemical-name/formaldehyde-in-pressed-wood-products.

wood or wood that is sustainably sourced and known to do well in a similar climate that is manufactured with CH_2O-free glues has immediate environmental benefits. Reclaimed wood retrieved from older buildings that used old-growth trees gives this wood a second life, saving trees from being lumbered, preserving delicate ecosystems, and maintaining as much CO_2 sequestration from older forests as possible. Building with certified sustainably sourced woods ensures that the wood being used is coming from an area that is managed in such a way that ensures the mitigation of climate change, prevention of deforestation, and preservation of biodiversity and local ecology.[257] By committing to building with solid wood or engineered flooring that uses soy or other plant-based binders, both environmental impact and human health concerns can be minimized.[258]

System Longevity

Similar to Frank Lloyd Wright's Usonian house, designs like the tiny prototype by Jessica Gjerde and her team, Joseph Brown's relief house, and Kathryn Schenk's Flex House focus on affordable, prefabricated units with off-grid technologies and could be instrumental in providing efficient relief housing for victims of disastrous hurricanes like Katrina and Harvey. Using passive, self-contained, off-grid housing with prefabricated, high-quality components that are easily transportable, require small teams with minimal equipment to

[257] Sustainability For All, "Why Is Certified Wood Important?" (Acciona), accessed November 24, 2018, https://www.activesustainability.com/environment/why-is-certified-wood-important/.
[258] Victoria Schomer, "What Is Truly the Healthiest Wood Floor Option, and What Are the Safest Finish Products to Use?" (Green Home Guide, 2009), https://www.greenhomeguide.com/askapro/question/what-is-truly-the-healthiest-wood-floor-option-and-what-are-the-safest-finish-products-to-use.

assemble, that can be disassembled and reused, can save valuable resources such as time, money, and materials.

Taking a cradle-to-cradle life cycle approach by using techniques such as the ones used in these designs offers a solution to the problem with disposing of the trailers once they are no longer needed, as they can be broken down and stored for the next inevitable demand for relief housing or they could be put into circulation as a solution to house homeless people not associated with the disaster, putting the units and services to good use in the interim. Additionally, by using sustainable materials that can be recycled and reused after the housing units are out of commission due to age, the imprint left on the planet can be minimized.

4.3 Social Factors

Toxicity

In the case of the formaldehyde-laden trailers, the issue was the binders used on the pressed wood products utilized in constructing the units, while in the Make It Right housing, wood was an issue because of the TimberSIL used. Both instances generated health and safety concerns that could have been avoided by using better materials and design choices. Although formaldehyde is commonly used in many household items, exposure can normally be controlled through ventilation, air filtration, and indoor temperature control; additionally, CH_2O containing materials will emit less gas on their own if given

enough time to set.[259] Travel trailers generally have few means of ventilation and introducing fresh air into the space and have limited ways of guarding against temperature extremes due to minimal insulation.[260] In addition to these inherent characteristics of trailers, the units built for FEMA were done so in such a hurry that proper care was not able to be taken to ensure the built up gasses from the new resins used in construction were able to be eliminated.[261]

According to a study done on temporary housing units by the Environmental Energy Technologies Division in the Indoor Environment Department at the Lawrence Berkeley National Laboratory in 2010, it was found that an 18 degree Fahrenheit (10 degree Celsius) variation in temperature increases CH_2O emissions by a factor of 1.9-3.5 and a 35% increase in humidity causes a similar, though slightly less significant increase of 1.8-2.6 times.[262] New Orleans ranges from average temperature lows of around 50 degrees Fahrenheit (10 degrees Celsius) in the winter and highs of 90 degrees Fahrenheit (32 degrees Celsius) in the summer;[263] the city averages a yearly relative humidity between 61-88%.[264] According to these data, it can

[259] Michael D Shaw, "Formaldehyde: It's Not Only Found In FEMA Trailers," 2008, https://www.gasdetection.com/interscan-in-the-news/formaldehyde-found-fema-trailers/.
[260] R G Liteplo et al., "Concise International Chemical Assessment Document 40: Formaldehyde," 2002, http://www.who.int/ipcs/publications/cicad/en/cicad40.pdf.
[261] Heather Smith, "People Are Still Living in FEMA's Toxic Katrina Trailers — and They Likely Have No Idea," Grist, 2015, https://grist.org/politics/people-are-still-living-in-femas-toxic-katrina-trailers-and-they-likely-have-no-idea/.
[262] Srinandini Parthasarathy et al., "Effect of Temperature and Humidity on Formaldehyde Emissions in Temporary Housing Units," 2010, https://escholarship.org/uc/item/4q99c791.
[263] US Climate Data, "Climate New Orleans - Louisiana and Weather Averages New Orleans 1961-1990 Normals."
[264] Current Results, "Average Humidity Levels for Louisiana 1961-1990 Normals," 2018, https://www.currentresults.com/Weather/Louisiana/humidity-annual.php.

be concluded that the average CH_2O level of 77 ppb in the FEMA trailers[265] could jump as high as 269.5 ppb for every 18 degrees Fahrenheit (10 degrees Celsius) the temperature climbs.

Thermal Comfort

The thermal environment in temporary relief housing has been found to have a significant impact on disaster victims' overall body function. According to Wang et al. in their study done on disaster victims and their living environment, the victims surveyed suffered from sleep deprivation and reduction of appetite, as well as increased frequency of illness. These factors contributed to negative effects on both the physical and mental state of victims living in relief housing. The study demonstrates the major significance proper thermal regulation inside relief housing has on victims' health. The researchers found that without proper ventilation and temperature control, disaster victims suffer in many ways that are both physically and mentally taxing.[266] This contributes not only to the potential for legal action as was seen in the aftermath of Hurricane Katrina but also a higher cost to society due to the increase in demand for medical assistance.

[265] Centers for Disease Control, "Formaldehyde Levels in FEMA-Supplied Trailers Preliminary Findings from the Centers for Disease Control and Prevention," 2008, https://web.archive.org/web/20080611220238/http://www.cdc.gov/nceh/ehhe/trailerstudy/pdfs/SummaryofStudyFindings.pdf.

[266] Wang et al., "The Influence of the Deteriorations in Living Environments on the Health of Disaster Victims Following a Natural Disaster," 209.

Social Capital

Ochoa and Capeluto reinforce the importance of working with a variety of stakeholders in their study on strategic decision-making for intelligent buildings, showing how gaining valuable insight from more than one source can contribute to a holistic understanding of the challenge. Knowing the challenges allows clear objectives to be defined and the best plan of action to be taken from the beginning of a project rather than being forced to correct mistakes late in the process after encountering several failures resulting from poor decision-making. It is apparent that these strategies were not put to use by FEMA in handling the procurement of trailers used for disaster relief victims but also in the attempts made by MIR to provide sustainable housing after Katrina.

Involving the community in the affected area can help to determine the services needed, what resources are available, and establish social capital by building trusting relationships between storm victims and leadership. Rajib Shaw and Yuko Nakagawa show this strategy to be effective regardless of income class of the affected region. Lowernine.org has proven that local efforts and volunteerism is extremely effective in rebuilding after a storm. The relationships formed and utilization of community members and local businesses helped them to become one of the most successful movements to restore the neighborhood. Strong social capital is an apparent advantage that this organization had over FEMA, MIR, the Katrina Cottages, and many other efforts to bring relief to the victims of Hurricane Katrina.

4.4 Importance of Home and Culture

The Lower Ninth Ward suffered significantly after Katrina, not only from a lack of organization by FEMA or failed experiments of wealthy businesspeople attempting to rebuild houses, they suffered from a lack of services such as schools, businesses, restaurants and grocery stores, and places to socialize. The Lower Ninth was no longer a functional place to live, which led to a sweeping abandonment by many people who had once called it home. This lack of support for low-income neighborhoods is not new, it happens often enough to be expected – it is almost systematic. When an area is so devastated by poverty and ruin, it leaves the land open for development. While many people likely prefer to have elegant buildings, chic businesses, and beautiful green spaces, these features often attract people in higher income classes, forcing lower income residents out of their homes and communities because they are no longer able to afford to live there. This gentrification and subsequent displacement could be avoided more successfully if better relief and recovery efforts were provided to victims immediately following a storm.

The study done by Rivlin and Moore on the supports and barriers to the process of home-making concluded that the environment in which people live has an enormous impact on health and well-being. The process of home-making was found to be complex and require many different forms of support in both physical and emotional aspects, especially when helping to reacquaint homeless people with the familiarity and comforts needed to feel at home.[267] A

[267] Rivlin and Moore, "Home-Making: Supports and Barriers to the Process of Home," 334.

home is much more than a place to sleep, it is a place for connections to be made and for people to gather, raise families, and socialize with friends – these are also factors that are unique within different cultures. By establishing a connection with the local community, government agencies can learn and accommodate for cultural necessities. Fostering the rebuilding of the environment surrounding a neighborhood can help to repair communities and strengthen victims' lives in a way that a relief shelter on its own could not.

Although Charlie Kilman noted that it may be difficult for the average American to choose to live in a tiny house, storm victims are operating under different circumstances and are often faced with the choice of being homeless or living in a government provided trailer. This research uses a 240 square foot (22.3 square meter) trailer as an example of FEMA provided relief housing, a size which is within the range of tiny house classification. Tiny homes are often made with higher quality materials and designed to look, feel, and operate as a small version of a traditional home, rather than a temporary living environment. This upgrade from travel trailer to tiny house could offer the culture change needed to happen to not only accept tiny houses as viable for short-term hurricane relief, but to choose tiny housing moving forward in life, long after the recovery period has ended.

4.5 Design Strategy

Applying the Integrated Design key topic of IPD by opening communication between FEMA, the local community, disaster victims,

businesses in the area, and the designers and engineers contracted for the project, would prove to be a more effective strategy for establishing relief housing, reducing costs, and ensuring the needs of the community are met. By forming an Integrated Project Team that is focused on a holistic strategy, rather than evaluating and improving components individually, many difficulties can be foreseen and prevented. Having each discipline involved from the beginning allows for problems to be identified and addressed before moving forward in a project; approaching the design of a building in this manner, the structure can be optimized for health and energy efficiency before being built.

Focusing on design strategy, the process of manufacturing, delivering, assembling the components, and creating strong social capital can be transformed into an efficient system that can help to improve the lives of storm victims and prevent unnecessary cost to society. The Okala Eco-design Strategy assists designers with brainstorming and helps them to ensure materials, waste, and energy expenditures are considered thoughtfully throughout the entirety of the life cycle. While it is important to understand that this strategy has limitations in application, the purpose is to act as a tool for designers to expand their minds and always be aware of options that are considerate of waste and longevity. For this reason, the Okala Eco-design Strategy can be of assistance in creating a solution for providing quick, efficient, quality disaster relief housing to those in need after a hurricane.

4.6 Findings

For the purpose of this research, a hypothetical 150,000 units are assumed to have been needed to fulfill the demand for relief housing. Due to the discrepancies in available data, this research uses the lowest credible cost of a FEMA trailer at US$24,162[268] (adjusted for inflation) and a size of 240 square feet (22.3 square meters). An average of US$53.31 is used for total monthly utility costs per unit, which includes electricity and water. The annual cost per unit for utilities amounts to US$639.72. This brings the total theoretical cost of relief housing for the first year after a hurricane for 150,000 units to approximately US$3.72 billion (US$24,801.72 per unit). The average cost of a 240 square foot (22.3 square meter) tiny house was found to be US$14,023.02, however with the addition of off-grid technologies the total used for this study is US$22,375[269]. The additional US$8,351.13 provides the necessary budget to allow for these technologies, which are an estimated US$2,451.13 for a solar panel system with battery backup and US$5,900 for a greywater recycling system while keeping the unit price at approximately US$3.35 billion.

	FEMA TRAILER	TINY HOUSE
Cost (per unit)	24,162.00	14,023.02
Utilities (per unit)	639.72	8,351.13
Total (150,000 units)	3,720,258,000.00	3,356,122,500.00

Figure 7. Housing unit cost comparison in US$ for the first year.

[268] Amount is rounded to the nearest dollar.
[269] Amount is rounded to the nearest dollar.

It was found in this research that off-grid tiny houses, after one year of use, could have saved the government US$364 million, assuming 150,000 units were needed. Further, after 10 years of use, assuming all monthly utility costs for traditional FEMA trailers remain the same, the 150,000 tiny houses could have saved US$959.58 million in utilities alone. The savings could contribute to other services that are greatly needed to make the recovery process more effective.

Both Hurricane Katrina and Hurricane Harvey required an extensive amount of resources from the entire country in the form of money, time, and materials, as well as work hours by victims, the local community, federal agencies, for-profit and non-profit organizations, and volunteers. The effects of each of these disasters were long-lasting, particularly in the case of Katrina where the shock of the event is still felt by many over a decade later. One of the notable system failures in post-Katrina relief housing was that by using travel trailers rather than exclusively using MHUs, HUD regulations did not have to be applied to the units. Had all units been taken off their wheels and placed in communities above the floodplain, they would have had to comply with safety standards for long-term housing. This detail could have prevented huge expenses for deactivation of toxic trailers and reissuing of new trailers and millions of dollars in lawsuits. This could have also saved many people from becoming ill and save money on countless medical bills paid for by the victims and insurance companies.

In addition to considering the type of units used and recognizing the reasons HUD has regulations for long-term housing, by using passive design techniques that allow for ventilation and proper regulation of indoor air temperatures as well as non-toxic materials and local resources, the buildup of toxic gasses could be prevented, and disaster victims could be free from health complications resulting from relief housing. The inclusion of passive techniques allows for proper ventilation and by understanding the importance of careful design using safe and reusable materials, the mental and physical health of the victims living in relief housing could improve drastically. In addition to the human health benefits these design changes allow, the average amount of CO_2 per annum saved could amount to as much as 457.35 million lbs (207,450.47 metric tons), reducing the amount of greenhouse gasses introduced into the planet's atmosphere. This could help in a small way to potentially reduce the intensity of hurricanes that occur in the future due to the changing climate. Lastly, by maintaining culture through proximity to family and neighbors, feeling a connection to the area, having security and feeling of ownership, and having the support of the community and access to educational services, people can begin to rebuild their lives more confidently and with better mental and emotional strength than were they only provided with housing without regard for these things. The final chapter discusses recommendations for implementing the solution that has been found and suggestions for further research and analysis.

CHAPTER 5: DISCUSSION

5.1 Implementation

Preparedness

Despite having already suffered through several destructive hurricanes of historic proportion since 2005 and making several well-intentioned changes as a direct result, there is still much that has not been learned in the way of prevention and recovery for disastrous storms such as Katrina and Harvey. As already noted in the NDRF under the principle of Resilience and Sustainability, this research has shown through various studies that involving the community and addressing the system as a whole allows for a more effective recovery. The implementation of this principle has been lacking in disaster recovery since the application of the new framework. Additionally, many of the changes were plans that involved what to do and how to rebuild after the damage has already been done.

Some matters that have not been addressed in coastal cities are the placement of homes, the extent of impervious surfaces, and the lack of stormwater management for heavy flooding. These are practices that if done in preparation for the next inevitable named storm, the magnitude of recovery effort that has been customary may no longer be needed. According to Peter Coy and Christopher Flavelle at *Bloomberg Businessweek*, Texas has “one of the nation’s most relaxed approaches to building codes, inspections, and other

protections."[270] Many builders in coastal cities want to expand as quickly and as inexpensively as possible, though this lack of standards can lead to poor planning and potentially hazardous and devastating consequences in the event of a hurricane. The planet is entering an era of more intense storms with higher rainfall,[271] and a city's lack of adaptation to the changing climate means only more expensive recovery efforts loom in the future.

While relief housing needs to be quickly retained and efficiently put into operation, acceptable health and safety standards are needing to be met. To avoid lengthy stays in temporary housing due to a lack of services needed for societal reintegration, it is critical that an effective recovery plan exists. Further, to reduce the negative impact on the environment and economy, careful consideration of materials and vendors need to be made in preparation for a disaster, rather than during response. Using resources such as time, money, and energy more thoughtfully, as Thoreau suggests, preparing ahead for inevitable events, could produce an efficient procedure for housing hurricane victims as well as provide a structured plan for helping them get back on their feet and out of relief housing, returning to society richer in knowledge and zest for life than perhaps they had been before the storm.

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[270] Peter Coy and Christopher Flavelle, "Harvey Wasn't Just Bad Weather. It Was Bad City Planning" (Bloomberg Businessweek, 2017), https://www.bloomberg.com/news/features/2017-08-31/a-hard-rain-and-a-hard-lesson-for-houston.

[271] Geophysical Fluid Dynamics Laboratory, "Global Warming and Hurricanes: An Overview of Current Research Results," 2018.

Adaptive Capacity

As Adger et al. suggest in their study of social-ecological resilience, adaptive capacity and social capital are the key contributing factors to successful disaster recovery. The case study provided by John Durston showed that for communities lacking in social capital, some effort needs to be made to find a connection and promote the building of relationships in order to establish an ability to function as a unit, leaving individualistic mentality behind, but after the steps to create these networks are taken, communities can come together to understand their needs and work toward a common goal. This suggests that some discovery of culture and what it means to be connected to one another has heavy influence on the building of social capital. It was also found that creating a strong link between community and government builds trust. Trust in leadership was found to be what led the Soni community, in Shaw and Nakagawa's study, and Village de L'Est, in New Orleans, to recover quickly after disaster. With trust in leadership, it is possible for a community to be of one mind, working together to develop solutions that will work for them economically, environmentally, socially, and culturally. In establishing these strong relationships, an effective system of governance can be formed that can create lasting, effective change, contributing to a resilient system.

5.2 Moving Forward

Recommendations

The entire nation can expect to see positive effects from demanding more resilient relief housing from federal entities, identifying the root cause of bottlenecks in the operation, and viewing relief housing as part of a larger system that requires a variety of services in order to rebuild a community after a disaster. It is important to acknowledge that government agencies have a reputation of repeating history several times over before establishing lasting change; this means that design teams need to be prepared to approach the appropriate entities within a policy window[272] with an exhaustive plan involving accurate cost, impact, and most crucially, a strategy for implementation. Having a plan for implementation in place, government agencies can maintain an organized process capable of reducing the negative impacts to budget, the environment, and society that can result from mismanagement of relief housing and recovery following a storm.

It is expected that by designing tiny houses with the intention of being off-grid, the limitations for unit placement and the expense associated with providing utilities to victims can be eliminated. Using prefabricated, off-grid tiny housing could help to streamline the process by having units ready for operation quickly without needing utility hook-up. Gjerde, Brown, and Schnek have drawn similar conclusions, as is evident in their designs for prefabricated tiny housing utilizing many off-grid technologies such as solar panels and large

[272] A policy window is an opportunity following an event that provides the most potential for policy change.

windows in addition to other design features that promote passive thermal regulation; the use of composting toilets and pump sinks have also been considered to accommodate an absence of running water. The designers acknowledge the difficulties in shipping and storing trailers post-Katrina, offering a solution by making the units modular and easy to build, noting that each house can be assembled by a few people without the use of heavy equipment.

Although the literature suggests that successful reintegration into society requires careful consideration of the extensiveness of shared space, it could be beneficial to have a central hub where tiny house community residents can gather for social activities such as meetings, job training, and life skill courses. A central space could act as a place where storm victims can meet and exchange struggles and needs – gaining emotional support from people who have been through the same experience; this could help to form bonds in the same way the people from Guatemala were able in the case study done by John Durston. In addition to having an indoor space, an outdoor green space could be provided as well to promote health, giving residents a place for physical activity, and provide an area to enjoy time outdoors with neighbors. Further, a work program could offer a way for residents to gain job experience while providing needed services for the community such as home maintenance or tending neighborhood gardens. Work programs could be a positive step toward self-reliance, lessening the amount of aid needed from outside the community.

A document assembled by the government of Puerto Rico after Hurricanes Irma and Maria in 2017 outlines an action plan to support a population that was largely neglected by its leadership in a time of need. This plan seeks to build trust between the neglected community and the US government by funding a recovery that focuses on repairing human welfare by supporting efforts that contribute to resiliency;[273] these efforts are made with the intention to limit emigration to the continental US and abandonment of Puerto Rico. One of the proposed actions is the creation of Opportunity Zones that specifically benefit people in lower-income areas through tax breaks for businesses in order to boost economic gains. This provision of funds is specifically intended for projects that address housing needs, economic revitalization, and development of infrastructure.[274] Using this type of plan along with promotion of the Tiny House Movement could help to provide areas that have been devastated, and are rebuilding, to begin setting the pieces in place to offer tiny homes as a solution for housing after a hurricane.

By incentivizing the Tiny House Movement with tax breaks, promotional campaigns, and policy change for zoning laws to better accommodate them in cities, the government can ensure that tiny house builders remain available. Encouraging people to become tiny homeowners by offering subsidized home loans specifically for tiny houses can help to create more demand for builders

[273] Government of Puerto Rico, "Puerto Rico Disaster Recovery Action Plan for the Use of CDBG-DR Funds in Response to 2017 Hurricanes Irma and Maria," 2018, 12, https://www.cleanegroup.org/wp-content/uploads/PR-Disaster-Recovery-Action-Plan.pdf.
[274] Government of Puerto Rico, 14.

and facilities that are able to make them. Having tiny house builders located in more areas around the country ensures the ability to provide them when needed. By subsidizing the tiny house industry, allowing the ability to scale up production and create them much more quickly, the government can use their established relationship to allow for production if needed following a storm. This eliminates the scramble to find contractors to design and manufacture trailers. Prefabricated components for tiny houses allow for quicker turnaround time and easier shipment, creating a more efficient method of obtaining and installing the homes. Maintaining relationships with tiny house builders in the affected area creates a link, opening access to the internal bonds and bridged groups of the local community. This relationship benefits the government by providing a more economical solution to disaster recovery while it helps the community in several ways: providing a new industry, creating jobs and promoting economic development; supporting the environment and human health through well-designed housing; and strengthening and supporting culture with sustainable solutions to the specific needs of the areas involved.

Future Research

Due to the lack of transparency about the emergency housing issued by FEMA, the scope of this research ends with the Okala strategy for developing a conceptual design, as the inventory for a trailer would need to be assumed, thus skewing the data unfairly depending on materials chosen for assessment. Similarly, an LCA for a tiny house would be entirely dependent on a fabricated inventory, as the features and functions incorporated into the design would not

be available until further into the process. The intention of this research is to offer concepts and recommendations for relief housing and because of this, the Okala strategy serves as an appropriate cut-off, offering a more qualitative understanding of what can be done to create a closed-loop system until further, more quantitative measures can be done following the design and construction of a prototype. While the strategies and technologies discussed in this research provide a conceptual understanding of sustainable housing for post-hurricane relief and recovery and implementation for a solution, an LCA is an extremely valuable technique when pitching an idea of this magnitude because it provides definitive results showing the impacts to human health and the environment. A sensitivity analysis following an LCA would be effective in determining the impact of different components of the system. Distinguishing factors that contribute to the sustainability of a system from factors that have little effect can help to pinpoint areas that would create the most meaningful change. From the results of a sensitivity analysis, policy makers could gain a better understanding of how decisions can influence their budget, the environment, and the people affected. Surveying policy makers could be an effective next step for gaining understanding of what would need to be done to ensure these steps toward implementation of a solution are taken. Knowing what factors contribute to success within a policy window could assist the integrated project team in determining what factors would influence a decision. In addition to surveying policy-makers, a scenario analysis could be used to

determine what potential outcomes are possible with the implementation of these recommendations.

Conclusion

The intention of this research was to discover if there is a more sustainable solution for disaster relief housing than the trailers that have been used in the past and if there is, what can be done to "close the gap" between the provision of disaster relief housing and the implementation of an effective solution for long-term recovery. The first question focuses on planning, design, and collaboration, using decision making tools and strategies such as the Okala Eco-design Strategy Wheel and the Integrated Design Approach. Using the Integrated Design Process, a team of people with various backgrounds and experience can pool their knowledge to establish goals in the early stages of design, working to solve problems before they become problems. The Okala Eco-Design Strategy can help the design team to identify areas of waste and seek to create a closed loop where all elements of the design can be repurposed, recycled, or disposed of with as little impact to the environment or human health as possible.

Establishing these intentions allowed for purposeful research to be done regarding housing size, energy efficiency, off-grid technologies, thermal regulation, and the health implications of using certain materials. The literature shows that smaller homes outperform larger homes in efficiency, regardless of energy standards, and that an overall reduction in environmental impact can be had by reducing housing size. Further, by using off-grid

technologies that are not dependent on the regular use of fossil sources, a house can offer net-zero carbon emissions, saving an estimated US$364 million and 457.35 million lbs (207,450.47 metric tons) of CO_2 in the first year of active use compared to the estimated costs of 150,000 FEMA trailers. Using high quality materials with natural adhesives in addition to producing intelligently designed prefabricated components could allow for proper ventilation and air flow, contributing to safer units that do not present a risk to the health of inhabitants.

To establish a plan for the implementation of off-grid tiny homes for relief housing, literature was reviewed regarding the importance of social capital for successful recovery and reintegration into society. The research shows evidence supporting that communities with strong social capital and trust in leadership experience more successful disaster recovery, regardless of income. In areas without established networking, social capital can be built by discovering commonalities among small groups. By promoting benefits to smaller groups, a community mindset can be formed which can help in actively setting goals and determining needs. Social bridging between a community and organizations outside of the community has shown to be effective in keeping communities safe by preventing negative usage of social bonding capital. Opportunity Zones, such as those proposed in Puerto Rico, could be used along with government home loan subsidies and tax incentives to promote the growth of the Tiny House Movement. By supporting this industry and maintaining relationships

with manufacturers, a plan for scaling up production in time of need can be carried out.

Thoreau's time in the woods may offer a valuable foundation upon which the government can build a plan for relief housing. The concept of "alternative economics" is something to be considered when planning for long-term disaster recovery. Were smaller, more economical and efficient houses used in lieu of the more expensive trailers of the past, the savings could be allocated elsewhere, such as education and services to help people reintegrate back into society. Based on the estimated calculations and the literature reviewed, which have provided evidence of economic, environmental, social, and cultural benefits, it can be concluded that there is a more sustainable solution for disaster relief housing than the trailers that have been used in the past. Further, this research suggests that there is a direct relationship between establishing social capital and the ability to "close the gap" between the provision of housing and the implementation of a solution for effective hurricane recovery.

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