WETWORK: Enabling escape from flooding urban spaces

by
Ross C. Cameron

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Industrial Design, School of Design

Pratt Institute
June 2022

WETWORK

A Pratt Institute thesis project by Ross Cameron

1

RESEARCH

Introduction

Floods are among the deadliest natural disasters experienced annually—killing, devastating and displacing people for all of human history, and before. What has been done and what is being done to address flooding? And how, as such an ancient problem, does flooding (especially in an urban environment) remain as widespread, deadly and destructive as it is?

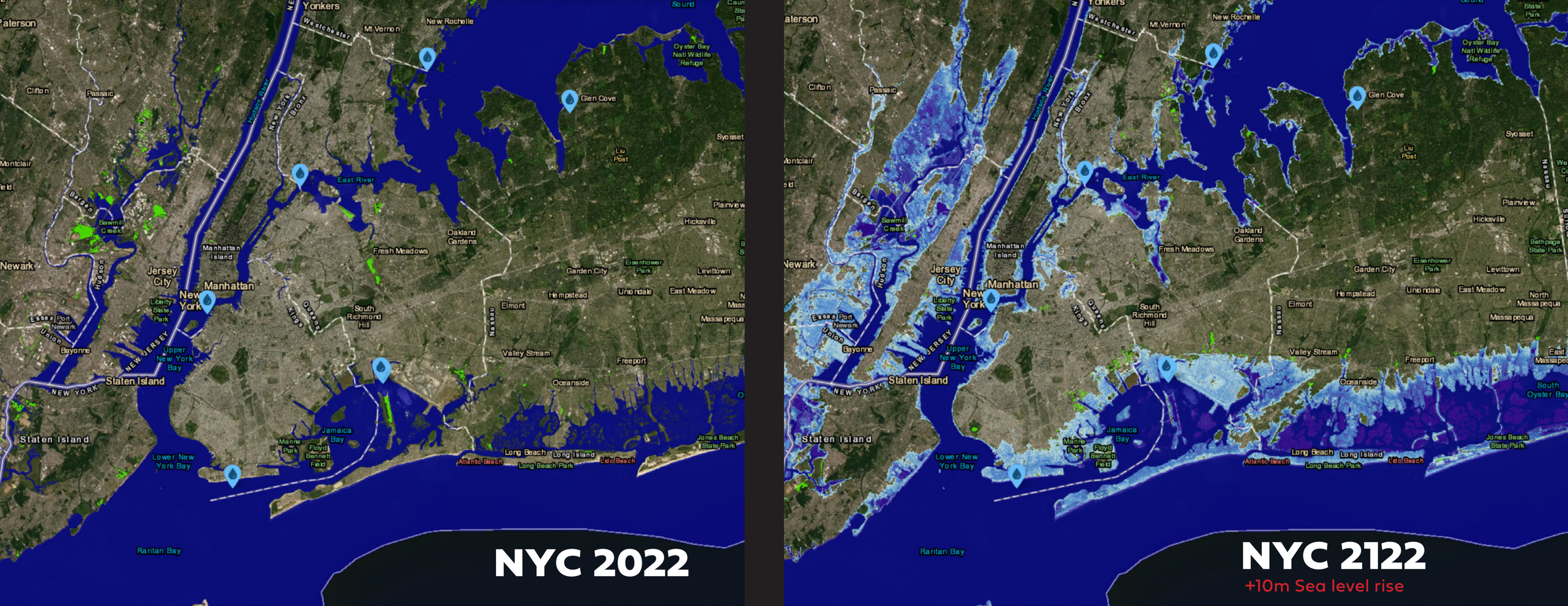
Of the ‘megacities’ in the world, many are increasingly susceptible to extreme weather events as climate change continues to wreak havoc on our cryosphere. Sea level rise, however, puts coastal and delta cities in a uniquely difficult position.

Share of housing in flood risk zone

Groundwater, coastal, and pluvial (or surface) flooding are much more prevalent and destructive in highly developed urban areas, and the effects of increased heavy rainfall events and sea level rise in some of these major coastal cities can be amplified. [1, 2]

One of the most notable examples of a city on the brink of a worsening flooding crisis is New York City, one of the most populous and economically developed cities in the world. Wetwork will focus primarily on New York and specifically on Brooklyn & Queens. This area is of marked significance because it has borne the brunt of the damage from the two most impactful flooding events in the past 20 years, and because it contains many areas in which architecture, urban planning, and geography align to create uniquely hazardous conditions during flash flooding events. [3]

[1] Montanari, "Socio-Economic Impacts under Different Sea-Level Rise Scenarios: Analysis at Local Level along the Coastal Area of Rome, Italy."
[2] Fox and Hara, "Water Rising: Equitable Approaches to Urban Flooding."
[3] Reed et al., "Increased Threat of Tropical Cyclones and Coastal Flooding to New York City during the Anthropogenic Era."


NYC 2022
NYC 2122
+10m Sea level rise

In a speech at Duggal Greenhouse in June of 2013, former NYC mayor Bloomberg noted that over 500 million square feet of New York City buildings fall within the Federal Emergency Management Agency (FEMA)'s current 100-year flood maps, including the homes of nearly 400,000 people, plus more than 270,000 jobs. Nothing has illustrated this fact better in the past decade than the major storms that have hit the region and revealed its critical shortcomings regarding flooding. The invaluable data and insight collected from Hurricane Sandy (2012) and Hurricane Ida (2021) guide this project and its foundational research.

Historical Precedents

Catastrophic floods have happened so often throughout human history that most cultures, religions, and historical records reference them. Some places where humans have developed are so prone to flooding that the very architecture of both the natural and urban environment has been shaped by it.

Canal cities like Venice, Rotterdam, Amsterdam, Bruges and Bangkok were developed and constructed with flooding and stormwater management in mind. Other cities, like Boston, Philadelphia, Washington D.C., New Orleans, and New York City however, were not designed to be regularly flooded, even those built along coastlines and coastal rivers. In many cases, floods were uncommon enough that they remained a nuisance rather than a pressing concern, and little was done to build resilience to future disasters.[4, 5]

---

[4] Jha et al., Five Feet High and Rising; Shi et al., "How Can Cities Respond to Flood Disaster Risks under Multi-Scenario Simulation?"; Abram et al., "IPCC Summary for Policymakers 2019."
[5] Shi et al., "How Can Cities Respond to Flood Disaster Risks under Multi-Scenario Simulation?"

What we now know that perhaps generations before us did not is this: an increase in cyclones[6], heavy rain events, storm surges[7], coastal flooding, extreme weather events and sea level rise due to climate change, means that, even in cities where flooding once seemed unlikely, a dire situation has developed and continues to worsen. Cities all over the world, including some of the biggest and most populous, are facing flooding so difficult to manage that they need to consider rebuilding entire swaths of urban landscape.[8]

Though our understanding of and familiarity with flooding may be rapidly changing, this does not mean that we can't learn and gain valuable insight from history. The Wetwork project focuses on New York City, which has accessible weather and historical records from as far back as extreme weather events were recorded with scientific regularity in the United States.

Settled by the Dutch—whose expertise in flood and stormwater control is globally recognized for its ingenuity[9]—New York City

[6] Roberts, Colle, and Korfe, "Impact of Simulated Twenty-First-Century Changes in Extratropical Cyclones on Coastal Flooding at the Battery, New York City."
[7] Hwang, "Stochastic Analysis of Storm-Surge Induced Infrastructure Losses in New York City."
[8] Abram et al., "IPCC Summary for Policymakers 2019."
[9] Pilkey, Pilkey-Jarvis, and Pilkey, "New and Old Amsterdam: New York City and the Netherlands."

faces a unique set of challenges when it comes to flooding and extreme storm surge events that, though rare, are amplified by New York Bite's right-angular geography and gain the potential to become extremely destructive.[10]

Though events that cause flash flooding are rare in NYC, they are well recorded throughout modern history—the first recorded 'megastorm' being the 'New York City' Hurricane of 1893, also known as the Midnight Storm, the most severe in recent memory being Hurricane Sandy which reached NYC in late October of 2012[11], and the most recent being the remnants of Hurricane Ida that wreaked havoc on the city and its flood-prone neighborhoods on September 1st and 2nd, 2021.[12] An effective summary of flood response to date in New York City can be established by reviewing the last two major severe storm surge events of the past decade, Sandy and Ida.[13]

[10] Coch, "Forensic Analysis of the 1893 'New York City' Hurricane."
[11] Kaufman, "NYC Does Well against Sandy, but Still Needs to Improve."
[12] Deliso, Katersky, and Lennihan, "Calls for Change after 11 People in NYC Basement Apartments Died during Catastrophic Floods."
[13] Depietri and McPhearson, "Changing Urban Risk."

Superstorm Sandy, the remnants of a powerful hurricane that hit New York City in October 2012, caused a severe amount of damage due to wind and primarily flooding in Manhattan, Staten Island, Brooklyn, Queens and Long Island, as well as parts of Northeastern New Jersey. Sandy took many New Yorkers by surprise, as severe coastal storms of this magnitude rarely reach the city, and a full moon the night of the storm influenced tides and greatly amplified the storm surge waters that inundated the city. Nearly 400,000 people were evacuated, 43 were killed by the storm, and tens of thousands were left without homes to go back to. Nearly a million people lost electricity, and billions of dollars of damage to homes, businesses, infrastructure, transportation and utilities were incurred. Sandy flooded many areas of New York City, hitting Lower Manhattan, parts of coastal Brooklyn, the Rockaways and Coney Island in Queens and a large portion of Staten Island. Many neighborhoods were completely cut off from transportation, and in some areas normally operating public transit did not return for several weeks afterward.[14]

[14] Kaufman et al., "Transportation During and After Hurricane Sandy."

These numbers show the severity of Hurricane Sandy, but not the issues that came to light because of it—the more valuable data, as I see it. Sandy revealed many pain points, realities, inequities and problems for New Yorkers, especially combined with, at this time, a relatively forward-thinking outlook on climate change which signaled that there was more to come. The government at the time put together several storm water management reports, and outlined plans for massive structural changes to utilities, stormwater management in many of the flood prone neighborhoods of the city, and in the inlets, harbors, bites and rivers themselves. Though some of these plans have started to undergo actual development, many are still being debated and worked out and their construction dates vary across the next decade.[15, 16]

Unfortunately, many of these plans were not realized in time for Hurricane Ida, which battered New York in September of 2021, killing 13 and flooding many neighborhoods across Manhattan, Brooklyn and Queens. Subways across the cities were flooded[17, 18], as well as were many street- and basement-level apartments. A record rainfall hit working class and immigrant neighborhoods the hardest[19], with 11 out of the 13 deaths being people living

[15] Gornitz et al., "Enhancing New York City's Resilience to Sea Level Rise and Increased Coastal Flooding."
[16] Aerts and Botzen, "Flood-Resilient Waterfront Development in New York City."
[17] Berg, "NYC's Subways Have a Built-in Tool for Preventing Floods. Where Was It Last Week?"
[18] Hersher, "NYC's Subway Flooding Isn't A Fluke. It's The Reality For Cities In A Warming World."
[19] Velsey, "Those Flooded Basement Apartments Are a Deadly Part of the Housing Crisis."

in basement apartments, many of them immigrants in illegally converted cellars. In response, the current Mayor has discussed creating a database of basement level and illegally converted cellar-level apartments, in an effort to get them converted to the legal standard already set forth by the city and prevent the type of drownings that occured during Ida.[20]

In terms of industrial design approaches to urban flash flooding and storm surge, there are few. Much of what is used to survive a flood and rescue those trapped in it has existed for centuries, with improvements in material, availability and variety overtime but with little major change. While most designs for sea level rise and flooding abatement are either infrastructural, architectural, or urban planning-level projects, these storms show us that there are many opportunities where industrial designers might intervene. Pilkey et al. outline in New and Old Amsterdam that "New York City is considering a number of projects to protect Lower Manhattan from further flooding, including Seaport City, a massive multipurpose levee that would simultaneously raise the shoreline to 19 feet above current sea level while expanding Manhattan some 500 feet into the East River." They also review a number of policy and planning initiatives, such as the NY Rising Community Reconstruction Program (NYCRCR) which focuses

[20] Holpuch, "New York Floods: Calls for Action after 11 Die in Basement Apartments."

on areas and specific properties in high-risk flood zones, seeking to buy out property owners and businesses in the most flood-prone areas in NYC, specifically large swathes of certain Staten Island neighborhoods. The NYC Department of Environmental Protection is also working on major sewage and wastewater management initiatives in several neighborhoods, including Gowanus, College Point and Canarsie.[21] Ongoing and proposed infrastructure and policy projects also include "hardening stormwater, wastewater, and other critical infrastructure to withstand climate impacts, and advancing nature-based solutions, such as wetland and forest restoration, to stabilize shorelines, reduce erosion, act as carbon sinks, and mitigate urban heat island effects[22] and subway tunnel flood gates at crucially vulnerable stations across the city, most likely to be shut down by a severe storm surge.[23]

Severe storm surge and the flooding that follows affect particular groups of vulnerable people such as the poor, immigrants, people of color and the elderly much more severely than others[24], which provides a more than adequate audience of stakeholders for whom solutions that both save and improve life could be created. As we enter the coming century, severe weather will become more common to New York City and all coastal cities[25], and eventually this vulnerable group will encompass a large percentage of residents of coastal cities, which is only more evidence of the dire need for a wide array of design solutions.

---

[21] McMullen-Laird, "How to Stop Basement Apartments from Becoming 'Death Traps' During Flash Floods."
[22] Zimring and Corey, "Conclusion: On the Rising Tide."
[23] Vermeij, "Flood Risk Reduction Interventions for the New York City Subway System: A Research on the Impact of Storm Surge and Sea Level Rise on the Safety against Flooding in Urban Deltas."
[24] Faber, "Superstorm Sandy and the Demographics of Flood Risk in New York City."
[25] Rahmstorf, "Rising Hazard of Storm-Surge Flooding."

Methodology & Methods

Research for Wetwork includes scientific papers on the topic of flooding, reports released by the Intergovernmental Panel on Climate Change, the Federal Emergency Management Agency, NOAA and more, videos, interviews, first hand accounts and live footage of previous hurricanes and floods including Hurricane Katrina, Hurricane Sandy and Hurricane Ida's effect on New York.

First hand accounts collected during Ida and displaying flooding in New York City basement level apartments and subways will also feature heavily.

The research and development of the project will take into account multiple perspectives, including that of survivors, emergency flood response experts, FEMA officials, city planning leaders, and those groups that stand to lose the most to flooding and sea level rise. Ideally, WETWORK will provide a solution that can benefit a wide array of actors in the effort to control and address flooding.

The scope of research for the project includes reports, articles, and references from the adjacent fields of climate science, toxicology, first response and rescue technology and practice, structural engineering, urban planning, transportation, demographics, oceanography and meteorology.

Wetwork will also focus closely on the urban environment. References and research will be gained from the field of Urban Studies, specifically through urban planning, zoning policy, urban climate change resilience and subterranean zoning and planning (often gleaned through a lens of public transportation e.g. subways). Though flooding can have a severe impact on exurban, suburban and rural areas, its impact on cities creates cascading and compounding hazards that have a simultaneously instant and protracted effect on daily life and many of the systems and institutions that support it.[26, 27]

[26] Rosenzweig et al., "Developing Knowledge Systems for Urban Resilience to Cloudburst Rain Events."
[27] Winters, "UFAA Report."

These problems also affect dense populations in more vicious and extreme ways.[28, 29, 30] Those living in cities are also more likely to become displaced, as the majority of city dwellers rent their homes or apartments.

The project will focus on an audience of stakeholders most impacted by the destructive and destabilizing nature of flooding, namely those who are truly displaced by the flood, and those who have, in losing their homes and becoming uprooted, been deprived of their livelihoods and the ability to recover from such an event. Specifically, the project will revolve around working class, minority and immigrant populations in particularly flood prone neighborhoods in Brooklyn and Queens, who are identified as being most vulnerable to severe urban flooding.[31] The Wetwork project utilized rigorous testing, prototyping, and user testing in order to truly approach a solution to flooding deaths in sub-street level apartments.

---

[28] Brake, "Rebuilding after Disaster."
[29] Verger et al., "Assessment of Exposure to a Flood Disaster in a Mental-Health Study."
[30] Lane et al., "Health Effects of Coastal Storms and Flooding in Urban Areas."
[31] Lai et al., "Life and Death Underground: N.Y. Immigrants Perish in Flooded Basements."

Based on interviews with EMTs, firemen and flood response technicians, initial viability of concepts and directions were determined, as a pre-user test to inform the latter actual testing.

Initial testing centered around the creation of a mechanism for a quick eject door hinge.

The mechanism will need to be tested for load bearing capabilities, how it performs against the pressure differential of water pushing against it, how it fits in with standard hinge measurements (following an investigation of the codes and standards in New York City), and how it is able to safely release the door, especially with a wall of water behind it.

Hinges will also need to be tested for crushing, bending and snapping strength, and hardness. An analysis of whether the hinges can be reused after ejection will also be performed. User testing on both options will also be performed, including a “real use” test for hinges, where a pressure differential simulating that of a flood will have to be produced in order for a user to test the opening of the door and ejection of the pin.

2

DEVELOPMENT

Introduction

For a period of time that far outpaces the entirety of recorded human history, individuals and communities have felt—and often were destroyed by—the shocking results of extreme weather events. Lightning storms, volcanoes, earthquakes, typhoons & hurricanes, and countless other iterations of severe, destructive and even deadly weather.

Our relationship with our surrounding environment and with the meteorological, however, is not one exclusively based on fear. As with most human expressions of understanding and many of our attempts to reconcile the natural origin of our species with the constructed latticework of the contemporary human experience, our relationship with weather is as complex as it is ancient.

Countless cultures, religions, and ethnic groups refer, for instance, to a "great flood" of incredible size, direction and destructive power. Many others have a lightning-wielding deity, a mercurial and wrathful sea god, and volcanic gods of power and mystery who control a force of both destructive and creative power.

Civilizational development, too, has been deeply impacted by forces of weather, especially seasonal and extreme flooding. These concepts lead inexorably toward a much more modern question about extreme weather that is also connected to questions about humanity itself raised often in the current global discourse:

Who deserves to be protected from extreme weather?

The two follow up questions that are most vital and the driving concepts behind this thesis projects are then:

Should wealth determine safety from severe urban flooding? And, do city, state, federal and other governmental agencies have a responsibility to protect low-income residents in vulnerable areas particularly prone to pluvial and storm-surge flooding?

Wetwork is primarily driven by the idea that all people—regardless of socio-economic, ethno-religious, or other backgrounds—deserve access to good design. Expanding on this idea, it is also my firm belief that, on a planet facing increasing severe weather and coastal flooding, socio-economic status should not be a determining factor in one's ability to endure and survive extreme flooding events or any other natural disaster.

To locate that statement in a more relatable context, Wetwork utilizes Hurricane Ida and the experiences of primarily low-income residents of Brooklyn and Queens as both case study and evidentiary support for the urgent need for an equalization of disaster prevention and response efforts across the geographically-bound socioeconomic strata of New York City. WETWORK also seeks to illuminate some key ways in which poverty across the globe, country, and city creates and catalyzes vulnerability to the myriad negative direct and knockdown effects of urban flooding events.

Through a year-and-a-half long process of research, field investigation and discovery, experimentation, sketching, prototyping, user testing, 3D modeling and printing, more prototyping and refinement to a final concept and form, the WETWORK project has been guided by and steeped in these questions and beliefs.

The Problem

Beginning simply with learning that an event which had caused me a slight inconvenience had actually claimed the lives of people in NYC was a difficult but potent catalyst for the Wetwork project.

After the mostly media-, publication-, and journal-based research presented in Chapter 1 was complete (to the degree that any design research can be completed), I adapted a more hands-on approach to meet the contracting scope of the project.

Several work problems and pathways of discovery were laid out before me at the outset:

- What about these spaces makes them problematic or dangerous in an urban flood scenario?
- Analyzing certain details / aspects of the spaces (through sketch model explorations to determine where an industrial design project might have the most impact.
- Analyzing more broadly, looking at what represents the average, “standard” version of these spaces (windows, doors, exit/entrance, depth below street level, etc.).
- Finding the most severe / impactful pain points amongst these, the door. Through primary accounts, news interviews, and direct quotes in articles from survivors.

Once I had progressed through and pulled common themes, experiences and problems from a multitude of accounts, an obvious area of focus became quite clear: the door. Survivor accounts were often from individuals in an identical situation to those who died, who so narrowly escaped drowning that they could describe the victims' experience from start to just shy of the endpoint, which unfortunately for 11 New Yorkers, was death by drowning.

Through a deep dive into written, recorded, and paraphrased survivor and witness accounts, I was also able to more clearly and effectively venture into the "experience" of these survivors, a perspective that proved quite difficult for me to gain, having never myself been trapped in a rapidly flooding space.

Stories told suggested—in no uncertain fashion—the type of experience that is so extreme, terrifying and swiftly unfolding that it can be comfortably classified as one of many events that one cannot fully understand unless one has experienced it firsthand.
Having little experience with extreme flooding myself, entering the mental space required to understand the situation from a design perspective required breaking down the problem into its most base, constituent elements. The initial discovery process required entirely

breaking down the incredibly complex "wicked" problem of flooding into its base constituent elements and issues. Though time-consuming, the process led to invaluable guiding design insights and questions, such as:

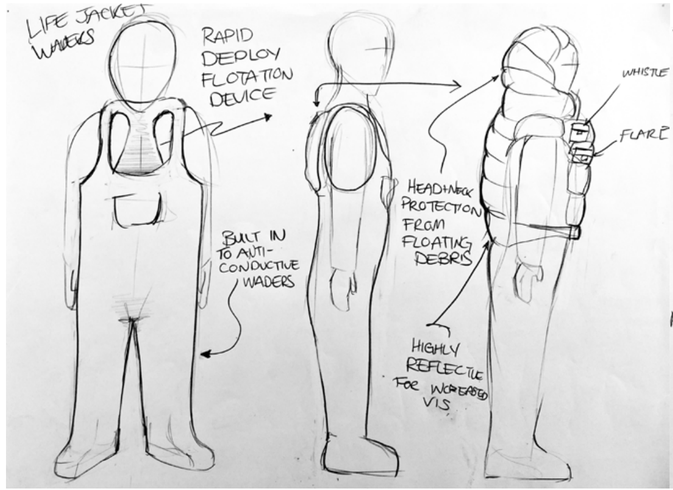
- What are the primary hazards in a flood?
- What are the leading causes of death in a flood?
- What are the dangers besides the obvious (drowning, physical trauma from floodwater)?
- What are the hazards of floodwater itself?

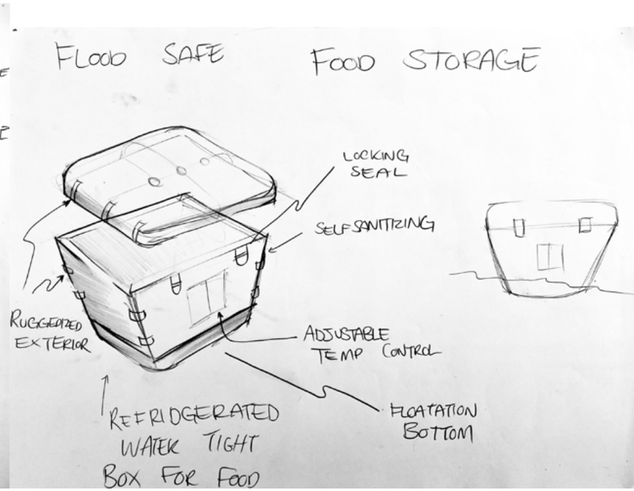
And, once I made the decision to use Hurricane Ida as a case study:

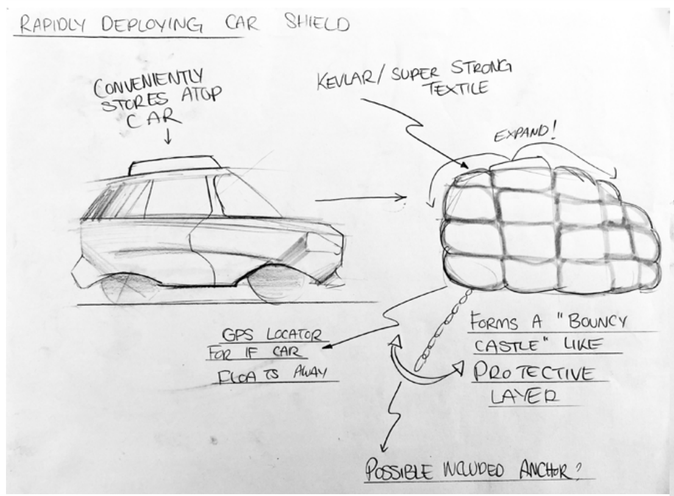
- What can survivors tell us about the experience of living through extreme urban flooding?
- Common points between multiple survivor / witness statements / accounts and — most importantly — why they occur.
- Common characteristics of the victims' (fatalities and survivors) space, e.g. the "illegally converted basement-level apartment"

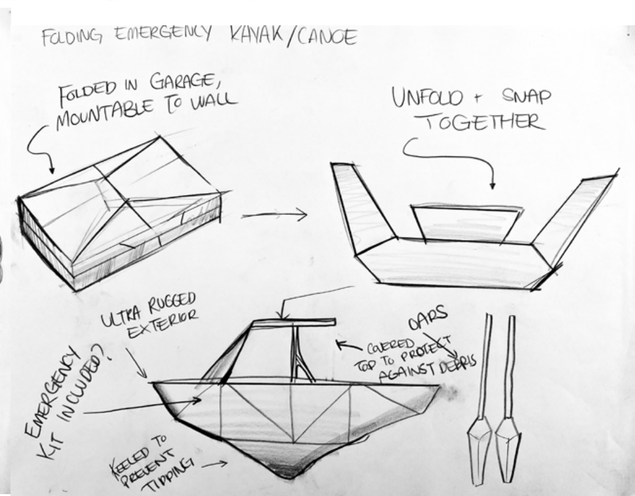
Early sketching, ideation and research revolved primarily around exploration of the problem areas and pain points that contained the most potential impact for an industrial design thesis project. My goal from inception was to create a project with a narrow enough scope and reasonable scale that it might be able to be easily manufactured with just slightly more resources than a grad student possesses.

Consequently, focusing the scope of research and ideation from a broader scope related to the consequences of urban flooding to a narrower yet closer look at a specific problem of extreme urban flooding using a recent hurricane as a case study became an important step in achieving feasibility for my project in the longer term.

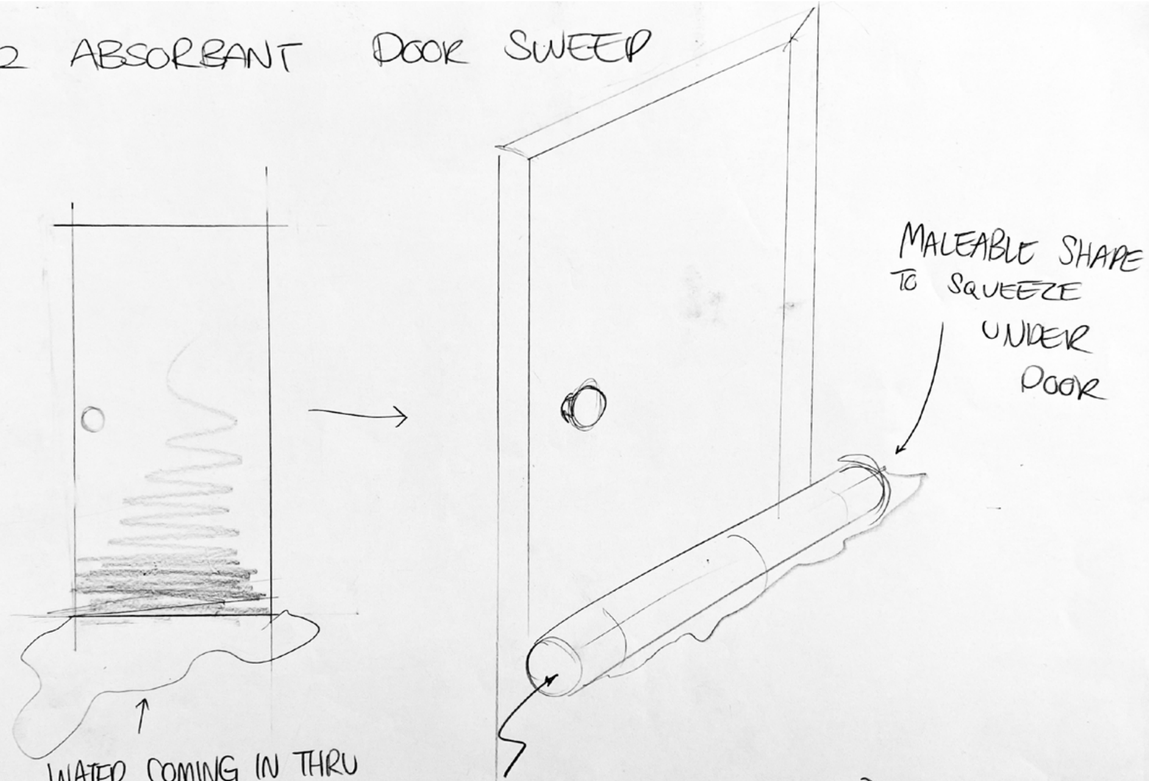


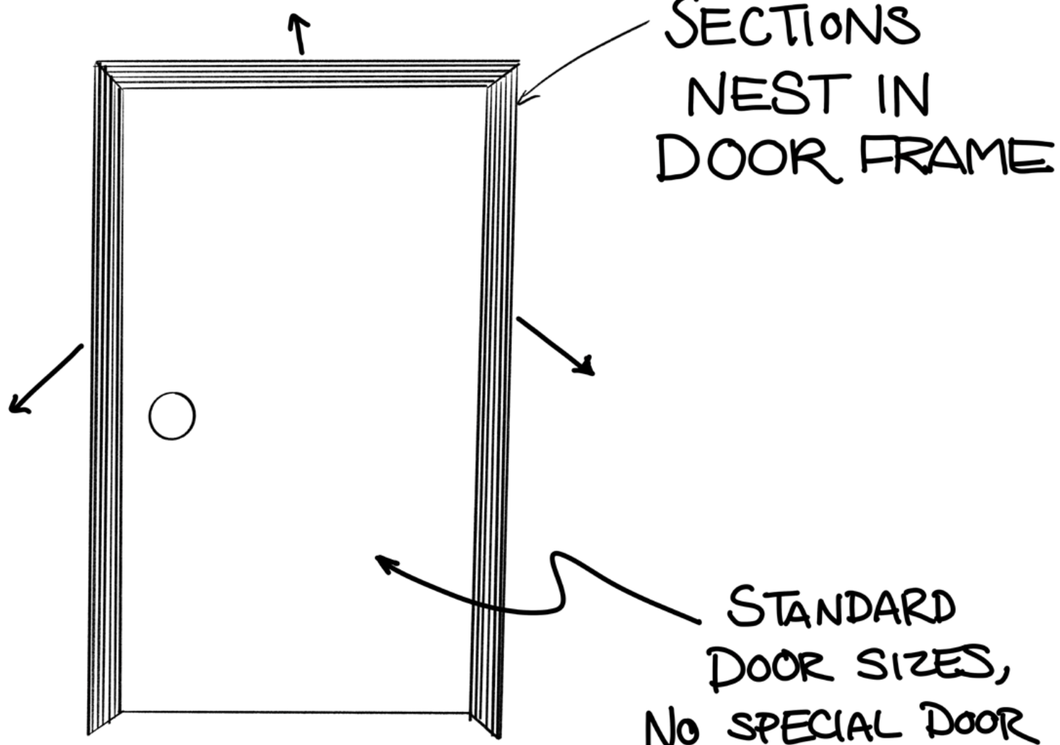


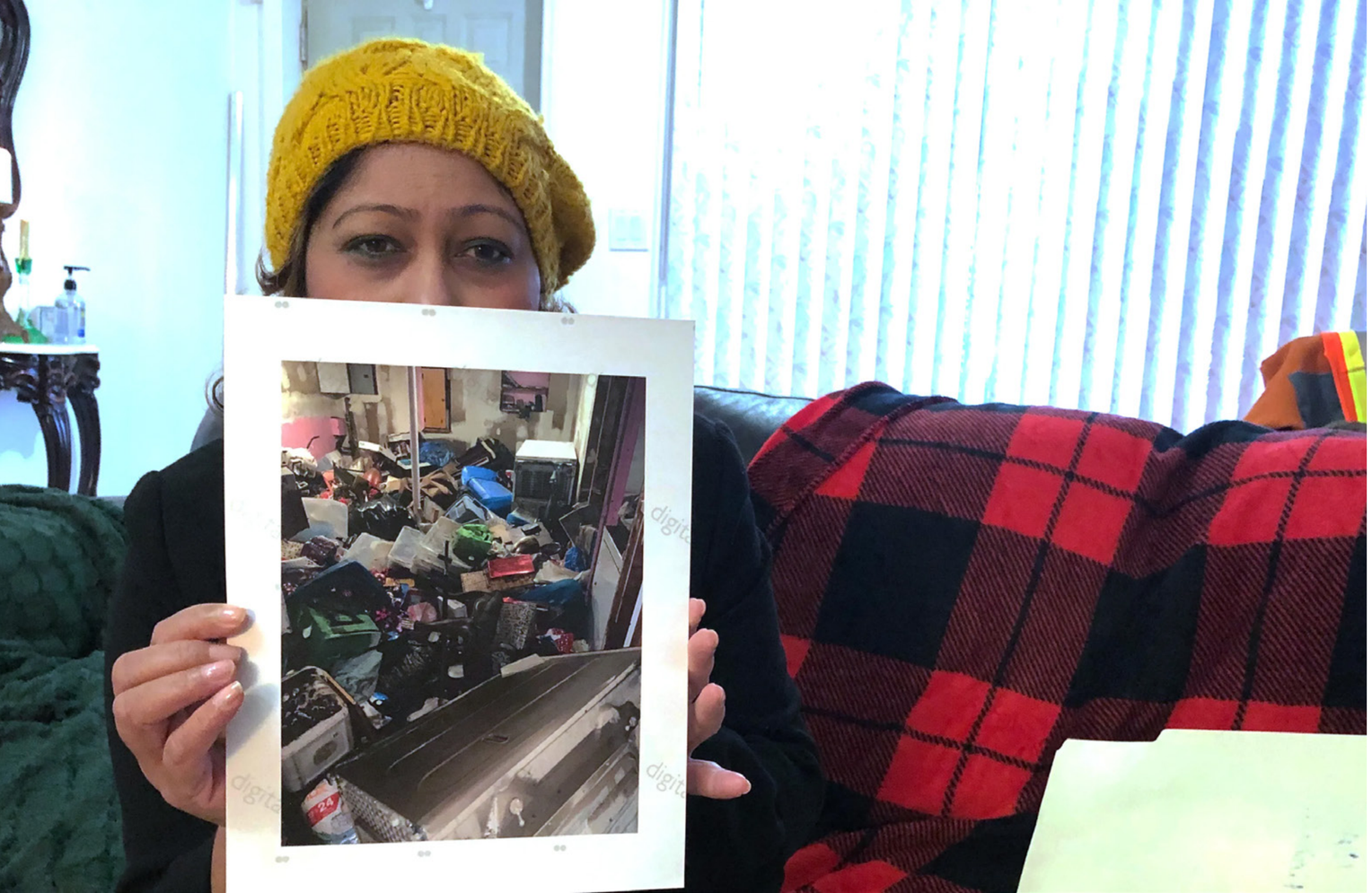




SUPER ABSORBANT DOOR SWEEP







Concluded from my investigation, the common pain points linking all occurances of this fatal disaster in Hurricane Ida in NYC are:

- Small, raised windows that don't provide an opportunity for escape in a flooding situation.
- Single point of entry/exit—e.g. no "back door"—generally leading in egress to a small, 'cut in' staircase leading down from street level. This space becomes a "well" in front of the only exit/entry point that quickly fills with floodwater in an extreme flooding event.
- Low ceilings which give a resident significantly less time to escape the space before drowning.
- Entire living space exists below street level, to a point where flooding is on some level inevitable.
- Generally cramped environments with little to no storage, resulting in a uniquely hazardous environment in an extreme flood like the ones seen during Hurricane Ida in Woodside, Queens.

The Solution

Wetwork enables escape, rescue and survival in three phases.

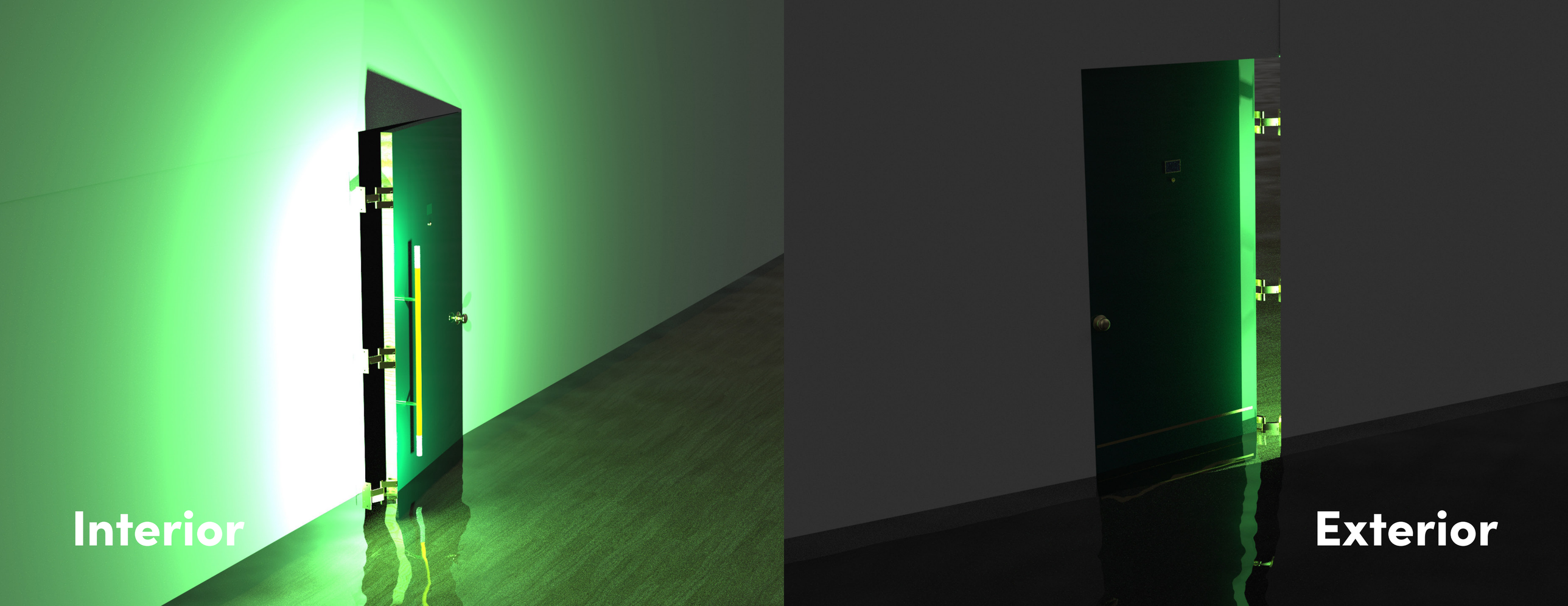
First, the door is equipped with a flood warning system that senses submersion and warns residents with lights (which also serve to guide the user to the exit in case of an electricity blackout) and an alarm.

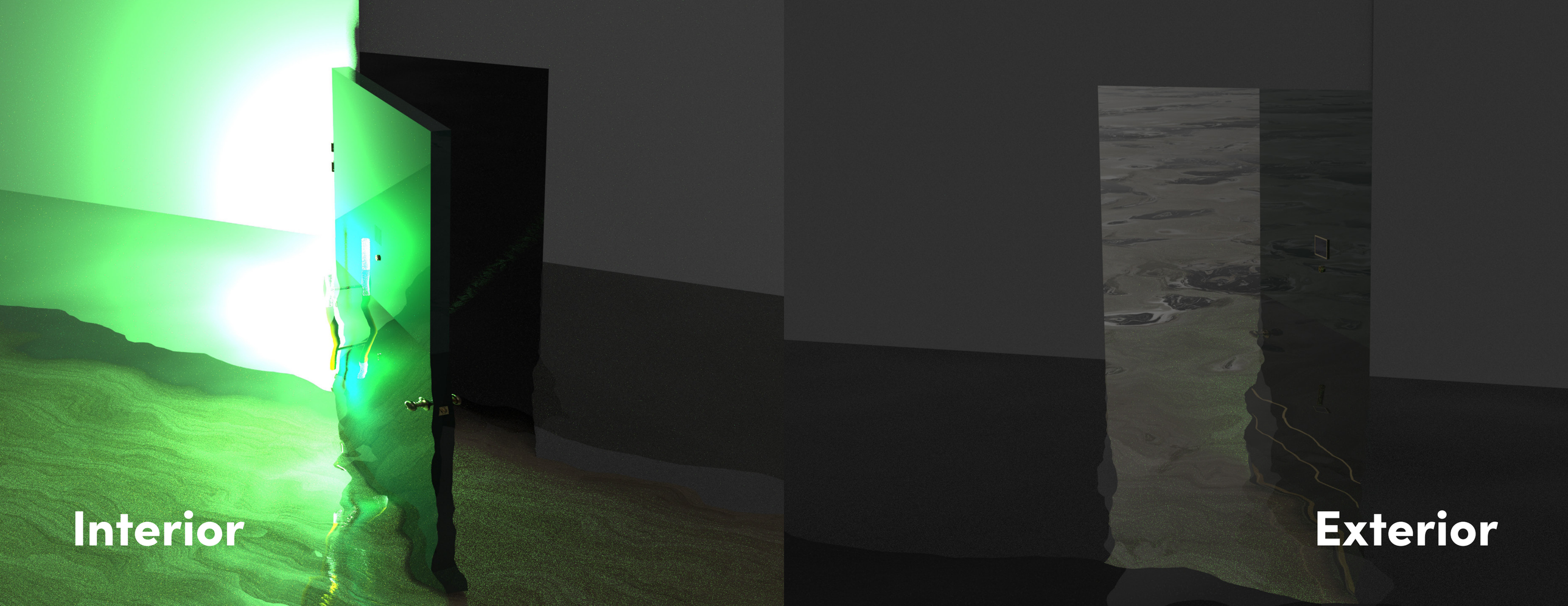
As the water rises, the door is sprung open on the hinged side to prevent a pressure differential buildup.

When a critical water level is reached, the bolt and pin of the door knob are automatically withdrawn, forcing the door open completely and allowing easy exit by residents and easy access (with far less danger) for EMTs and first responders attempting a rescue.


Interior
Exterior


Interior
Exterior


Interior
Exterior


Interior
Exterior

The Future

There are many possible avenues through which the WETWORK project can be further developed.

It is my hope that at the very least, the City of New York will see this project as a sign that feasible, inexpensive and non-policy and law based solutions exist for the seemingly intractable problem of urban flooding, one which NYC will be dealing with for many years to come.

I urge those viewing this project to also think of the futures that were stolen by the continued conversion, renting and existence of these deadly spaces. For the departed's sake, and for the sake of lives still very much in jeapordy in similar neighborhoods all across the country and globe, I hope to keep developing and realizing this project in order to help save and protect as many lives as I can.

3

APPENDICES

Notes

1. Montanari, Armando. "Socio-Economic Impacts under Different Sea-Level Rise Scenarios: Analysis at Local Level along the Coastal Area of Rome, Italy," 2016, 1–12.

2. Fox, Radhika, and Mami Hara. "Water Rising: Equitable Approaches to Urban Flooding." US Water Alliance, 2020.

3. Reed, Andra J., Michael E. Mann, Kerry A. Emanuel, Ning Lin, Benjamin P. Horton, Andrew C. Kemp, and Jeffrey P. Donnelly. "Increased Threat of Tropical Cyclones and Coastal Flooding to New York City during the Anthropogenic Era." Proceedings of the National Academy of Sciences 112, no. 41 (October 2015): 12610–15. https://doi.org/10.1073/pnas.1513127112.

4. Jha, Abhas, Jessica Lamond, Robin Bloch, Namrata Bhattacharya, Ana Lopez, Nikolaos Papachristodoulou, Alan Bird, David Proverbs, John Davies, and Robert Barker. Five Feet High and Rising: Cities and Flooding in the 21st Century. Policy Research Working Papers. The World Bank, 2011. http://elibrary.worldbank.org/doi/book/10.1596/1813-9450-5648.

5. Shi, Yijun, Guofang Zhai, Shutian Zhou, Yuwen Lu, Wei Chen, and Jinyang Deng. "How Can Cities Respond to Flood Disaster Risks under Multi-Scenario Simulation? A Case Study of Xiamen, China." International Journal of Environmental Research and Public Health 16, no. 4 (January 2019): 618–36. https://doi.org/10.3390/ijerph16040618.

6. Roberts, Keith J., Brian A. Colle, and Nathan Korfe. "Impact of Simulated Twenty-First-Century Changes in Extratropical Cyclones on Coastal Flooding at the Battery, New York City." Journal of Applied Meteorology and Climatology 56, no. 2 (February 2017): 415–32. https://doi.org/10.1175/JAMC-D-16-0088.1.

7. Hwang, Yunji. "Stochastic Analysis of Storm-Surge Induced Infrastructure Losses in New York City." Doctoral Thesis, 2013.

8. Abram, Nerilie, Caroline Adler, Nathaniel Bindoff, Cheng Lijing, and So-Min Cheong. "IPCC Summary for Policymakers 2019." Summary for Policymakers. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. IPCC, 2019.

9. Pilkey, Orrin H., Linda Pilkey-Jarvis, and Keith C. Pilkey. "New and Old Amsterdam: New York City and the Netherlands." In Retreat from a Rising Sea: Hard Choices in an Age of Climate Change, 51–63. New York, NY: Columbia University Press, 2016.

10. Coch, Nicholas K. "Forensic Analysis of the 1893 'New York City' Hurricane: Implications for the Future." Journal of Coastal Research 35, no. 4 (June 2019): 729. https://doi.org/10.2112/JCOASTRES-D-19A-00005.1.

11. Kaufman, Sarah. "NYC Does Well against Sandy, but Still Needs to Improve." Roads & Bridges, March 2013.

12. Deliso, Meredith, Aaron Katersky, and Mark Lennihan. "Calls for Change after 11 People in NYC Basement Apartments Died during Catastrophic Floods." ABCnews.Com, September 2021.

13. Depietri, Yaella, and Timon McPhearson. "Changing Urban Risk: 140 Years of Climatic Hazards in New York City." Climatic Change 148, no. 1–2 (May 2018): 95–108. https://doi.org/10.1007/s10584-018-2194-2.

14. Kaufman, Sarah, Carson Qing, Nolan Levenson, and Melinda Hanson. "Transportation During and After Hurricane Sandy." Rudin Center for Transportation NYU Wagner Graduate School of Public Service, November 2012.

15. Gornitz, Vivien, Michael Oppenheimer, Robert Kopp, Radley Horton, Philip Orton, Cynthia Rosenzweig, William Solecki, and Lesley Patrick. "Enhancing New York City's Resilience to Sea Level Rise and Increased Coastal Flooding." Urban Climate 33 (September 2020): 1–20. https://doi.org/10.1016/j.uclim.2020.100654.

16. Aerts, Jeroen C.J.H., and W.J. W. Botzen. "Flood- Resilient Waterfront Development in New York City: Bridging Flood Insurance, Building Codes, and Flood Zoning: Flood-Resilient Waterfront Development in New York City." Annals of the New York Academy of Sciences 1227, no. 1 (June 2011): 1–82.

17. Berg, Nate. "NYC's Subways Have a Built-in Tool for Preventing Floods. Where Was It Last Week?" Fast Company, September 2021.

18. Hersher, Rebecca. "NYC's Subway Flooding Isn't A Fluke. It's The Reality For Cities In A Warming World." NPR: All Things Considered. September 2021.

19. Velsey, Kim. "Those Flooded Basement Apartments Are a Deadly Part of the Housing Crisis." Curbed. September 2021.

20. Holpuch, Amanda. "New York Floods: Calls for Action after 11 Die in Basement Apartments." The Guardian, September 2021.

21. McMullen-Laird, Lydia. "How to Stop Basement Apartments from Becoming 'Death Traps' During Flash Floods." Gothamist. September 2021.

22. Zimring, Carl A., and Steven H. Corey, eds. "Conclusion: On the Rising Tide." In Coastal Metropolis: Environmental Histories of Modern New York City, 235–45. Pittsburgh, PA: University of Pittsburgh Press, 2021. http://www.jstor.org/stable/10.2307/j.ctv1hqdk4m.

23. Vermeij, D.A.A.N. "Flood Risk Reduction Interventions for the New York City Subway System: A Research on the Impact of Storm Surge and Sea Level Rise on the Safety against Flooding in Urban Deltas." TU Delft, 2016.

24. Faber, Jacob William. "Superstorm Sandy and the Demographics of Flood Risk in New York City." Human Ecology 43, no. 3 (June 2015): 363–78. https://doi.org/10.1007/s10745-015-9757-x.

25. Rahmstorf, Stefan. "Rising Hazard of Storm-Surge Flooding." Proceedings of the National Academy of Sciences 114, no. 45 (November 2017): 11806–8. https://doi.org/10.1073/pnas.1715895114.

26. Rosenzweig, Bernice, Benjamin L. Ruddell, Lauren McPhillips, Robert Hobbins, Timon McPhearson, Zhongqi Cheng, Heejun Chang, and Yeowon Kim. "Developing Knowledge Systems for Urban Resilience to Cloudburst Rain Events." Environmental Science & Policy 99 (September 2019): 150–59. https://doi.org/10.1016/j.envsci.2019.05.020.

27. Winters, Brad A. "Report for the Urban Flooding Awareness Act," June 2015.

28. Brake, Elizabeth. "Rebuilding after Disaster: Inequality and the Political Importance of Place." Social Theory and Practice 45, no. 2 (2019): 179–204. https://doi.org/10.5840/soctheorpract201942956.

29. Verger, Pierre, Michel Rotily, Claudine Hunault, Jean Brenot, Eric Baruffol, and Denis Bard. "Assessment of Exposure to a Flood Disaster in a Mental-Health Study." Journal of Exposure Science & Environmental Epidemiology 13, no. 6 (November 2003): 436–42. https://doi.org/10.1038/sj.jea.7500290.

30. Lane, Kathryn, Kizzy Charles-Guzman, Katherine Wheeler, Zaynah Abid, Nathan Graber, and Thomas Matte. "Health Effects of Coastal Storms and Flooding in Urban Areas: A Review and Vulnerability Assessment." Journal of Environmental and Public Health 2013 (2013): 1–13. https://doi.org/10.1155/2013/913064.

31. Lai, Stephanie, Vera Haller, Samira Sadeque, and Marc Fisher. "Life and Death Underground: N.Y. Immigrants Perish in Flooded Basements." The Washington Post, September 2021.

4

ACKNOWLEDGEMENTS

A special thanks to:

Ignacio Urbina Polo
Cecelia Fitzgibbon
Scott Cameron
Stuart Cameron
Elira Duro
Marguerite Smith
Vincent Ward
Danielle DuBois
Ruby Bullock

WETWORK

by

Ross Cameron

Received and approved:

Date June 07, 2022

Thesis Advisor Signature

Ignacio Urbina Polo

Thesis Advisor Name

Date June 10, 2022

Department Chair Signature

Constantin Boym

Department Chair Name