TRANSITION AS CONDITION:
TOWARD FLOOD RESILIENCE THROUGH
FLEXIBLE ARCHITECTURE

A Thesis in
Architecture
by
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ABSTRACT

Flooding is increasingly becoming an inevitable reality affecting communities around the globe. Following current urban planning and landscape design approaches, which challenge the exclusive application of hard-infrastructure projects and advocate the implementation of urban environments ‘making room for the water,’ architects propose solutions able to withstand the pressures exerted by flooding. This thesis focuses on these strategies, analyzing contemporary residential architecture for the floodplain, aiming to create a catalog of ideas for the design of houses better suited to cope with flooding. It also intends to unveil a paradigm shift in architecture, from the conceptualization of static structures, toward the design of flexible solutions that accept and incorporate the transitory condition established by floodwaters in the production of residential design.

The thesis presents the systematic analysis of twelve residential case studies located in the Netherlands, the United States, and the United Kingdom, exploring emergent built forms able to cope with flooding through structures that are raised, buoyant and/or permeable. Each house was analyzed through a set of parameters (Site, Structure, Skin, Program, Infrastructure, and Furniture), which allowed for the examination of architectural elements in each design and their later comparison.

The analysis shows that flexibility becomes a crucial component in the establishment of flood resilient architecture. It also concludes that, in order to sustain the daily lives and minimize the disruption of affected populations, architects must design houses able to physically withstand flooding, at the same time guaranteeing the continuous provision of access and utilities for their inhabitants. Furthermore, the research has unveiled that architecture for flooding generates unique housing typologies able to influence the way populations inhabit space. The dissimilarities between proposed and implemented case-studies additionally point to the fact that flood resilience can only be attained through the implementation of strategies at various scales, which are contingent to well integrated planning practices and building codes regulating development in floodplains.
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CHAPTER 1 INTRODUCTION

1.1 Background
A History of Urban Settlements and their Relationship to Water

Human populations have historically occupied the edge between land and water. The proximity to large water bodies assured humans with endless sources of fresh water, food, and highly productive land, which, rich in nutrients and biodiversity, created a perfect setting for communities to gather and thrive. Such fertile environments were always highly conditioned to their proximity to fluctuating water levels, which regularly deposited sediments and nutrients, renovating the land. As a consequence, rising tides have historically affected populations originated near to water, turning their natural geographic advantage into their biggest vulnerability. Flood events from all ages can be found in innumerous historic sources spread across the globe (van Beek and van Alphen 2006).

In spite of the dangers posed by flooding, societies adapted to the recurrent presence of water and evolved using their strategic locations as an asset for transportation and better connectivity (Hoornweg et al. 2010). As Charles W. Moore notes in his book “Water and Architecture”, “like veins and arteries, rivers and canals are waters of connection and communication” (Moore 1994, 77). According to the author:

“Rivers were important tools for developing societies, they helped trade to expand and prosper, sustained agriculture with irrigation, and supplied hydropower for mills and factories. Industrious societies used canals to link seas and oceans interrupted by the continent landmasses, to extend rivers, to pull the ocean inland, to connect lakes, rivers, and bays, and even to substitute for city streets.” (Moore 1994, 21)

With the growth of coastal settlements, however, floodplains were increasingly developed and largely occupied, leading the natural condition of rising tides to become “major society disrupting disasters” (van Beek and van Alphen 2006, 11). At the beginning of the 21st century, fifteen of the twenty world’s megacities are located in areas
adjacent to major water bodies, at risk from rising sea levels and coastal surges (Hoornweg et al. 2010). Currently, 13 percent of the world’s urban population lives in low elevation coastal zones (LECZ), less then 10 meters above sea level and particularly susceptible to flooding (McGranahan, Balk, and Anderson 2007). This number is only expected to grow in the years to come, as settlements located in coastal low lands continue to grow rapidly (McGranahan, Balk, and Anderson 2007).

In “FLOAT! Building on Water to Combat Urban Congestion and Climate Change” (2010), Koen Olthuis and David Keuning argue that the only way to increase a city’s density, in face of its fully developed urban core, is to push the margins of urban growth toward water.¹ At the same time, the attractiveness of living near water, once spurred by agricultural and industrious advantages, increasingly becomes a marketing feature for those aspiring to live in contact with nature. As population numbers increase in urban settings established adjacent to major water bodies, new housing developments are expected to occur closer to water, either by necessity or choice, on land highly susceptible to flooding.

Add to that current predictions of sea-level rise, the condition of recurrent flooding from high tides and storm surges will become more acute. As the temperature of the oceans increase and polar icecaps melt, the sea level is expected to rise an average between 18 to 38 centimeters in a low scenario, 26 to 59 centimeters in a high scenario, in the next century (IPCC 2007). William W. Hay, in a presentation given at the 2012 Geological Society of America Annual Meeting, argued that current sea level measurements already reach or exceed the maximum predicted by the 2007 IPCC Report, suggesting that a rise of 1 meter or more can be expected by 2100. Despite the debatable accuracy level of predictions for a future climate scenario, it is already known for a fact that Earth has become 0.8 degrees Celsius warmer and sea level has become 15 – 20 centimeters higher over the 150-year period of measurements (Oppenheimer 2011).

Urban environments are already experiencing the consequences of this new climate scenario and its influence on rising tides. In Venice, a city traditionally affected by the

¹ According to the authors, the expansion of cities not only will, but also must continue to occur, because people are the biggest source of prosperity for any urban settlement.
phenomenon of *acqua alta* (high tide), the winter floodwaters of 2012 reached 1.5 meters higher than normal, becoming the worst flood the city ever experienced since records began in 1872 (Mackenzie and Pullella 2013). Seventy percent of the lagoon city was under water, including its famous St Marks’ square, which, located in one of its lowest lying areas, became a giant swimming pool for tourists (Knight 2012; “Venice Under Water” 2013). Rising sea levels have recently become a more dramatic reality for the island populations of the Maldives and Kiribati, currently in the search for new land to secure a home for their 400,000 and 100,000 respective inhabitants. The Maldives faces the Indian Ocean, reaching its peak at 2.5 meters above sea level (Bergdoll 2011), while Kiribati struggles with the rising Pacific waters, threatening to submerge at least 50 percent of its urban territory in the next 40 years. Such examples testify to the fact that tidal flooding, a natural phenomenon experienced by some cities throughout their settlement’s history, will increasingly become a global event.

Recent floods around the world intensified the debate about measures to prevent human and material losses due to the temporary, and usually destructive, presence of water. The construction of protective barriers for New York and New Jersey is now being analyzed by local authorities, with precedents ranging from the 1982 Thames Barrier in London, to the currently under construction project MOSE in the Venetian Lagoon. Representing a traditional approach for the definition of boundaries between land and water, such hard-infrastructure projects are, however, increasingly challenged by researchers, urban planners, landscape architects, and architects. These “anti-barrier” advocates (Marshall 2013, 47) argue against solutions that can be easily “overtopped by events outside their design capacities” (Abhas, Bloch, and Lamond 2012, 32), which profoundly affect local ecologies, potentially dislocating the problem of flooding to somewhere else.

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2 “According to a World Bank report earlier this decade, Kiribati’s capital of Tarawa—where nearly half the population lives—will be 25-54 percent inundated in the south and 55-80 percent in the north by mid-century unless there is significant adaptation.” (“Tarawa” 2013)

3 In Brooklyn, New York, 25 homes were lost and 825 badly damaged due to the rising waters subsequent to Hurricane Sandy in October, 2012 (Carcamo, Hennessy-Fiske, and Pearce 2012); while in the United Kingdom, flooding events affected more than 800 households by November, 2012 (“More than 800 Homes Hit by Floods” 2012).

4 "A sea wall may protect the land immediately behind it but it also has the effect of exposing unprotected beaches on either side to greater erosion. Over time, as these beaches recede, the
According to Anuradha Mathur and Dilip da Cunha (2009, x), such hard-infrastructure projects reflect the “lens worn by administrators and the public: the lens of flood.” The authors sustain that fluctuating water levels causing temporary inundations have been traditionally perceived as something to be controlled. The measures adopted focused on strengthening boundaries to keep water in a pre-determined path, and “where necessary, keep the sea out” (x). The authors urge for the development of strategies that defy a consolidated idea of reinforcing boundaries, toward blurring the lines that currently attempt to divide land and water, creating “in-between” environments, both wet and dry. This approach signalizes a paradigm shift, determining a more fluid ground able to support more flexible and smaller scale interventions that engage with the transitory condition of rising tides.

Under such circumstances, architecture must be designed to “make room” for water, establishing resilient built environments able to withstand the impact of flooding and give continuity to the life of affected populations. Such resilient environments will be able to cope with the recurrent and temporary presence of water, adopting various forms in accordance to the ‘wet’ or ‘dry’ conditions of their terrains. If we combine urban growth toward water, often in the form of housing developments, with the condition of rising tides (either natural or aggravated by climate change), the necessity to study architectural responses to flooding becomes evident.

1.2 Problem Statement

Based on an increasing population settling near water bodies and the natural flooding conditions related to those, this research adopts the idea that the relationship between water and land, and consequently between water and the built environment, must and will become increasingly intertwined. As shown, static protective systems are not always capable of coping with severe flooding events. Hence, in order to protect human environments to flooding, architecture must become flexible, incorporating rising waters in the design of adaptable structures that differ in principle from the static solutions with protected land becomes a promontory and so becomes vulnerable to being outflanked by the sea unless further leeward defenses are built.” (Anderson 2009, 108)
which architects are so familiar.

Rooted in the concepts explored by contemporary planning initiatives and research projects in the United Kingdom, the Netherlands, and the United States, which focus on adaptation as means to develop softer-infrastructure\(^5\) and more permeable environments, the thesis aims to analyze the influence of the recurrent and temporary presence of water on the production of contemporary residential architecture.

### 1.3 Significance of Research

As the literature review will show, a detailed analysis of buildings adapting to the dynamic conditions of zones prone to flooding doesn’t exist. Hence, the thesis will contribute to fill this gap in knowledge. This research will perform a systematic analysis of contemporary housing typologies for flood-prone zones, contributing to a discussion still underdeveloped in the discipline of architecture and providing an array of ideas for future development in places affected by tidal flooding. The research is based on the hypothesis that a more flexible architecture is emerging with the ubiquity of floods and that houses designed through the lenses of flexibility are able to minimize the distress of affected populations, contributing to achieving resilience in flood prone-zones. Therefore, a deeper analysis of such typologies can provide insights on how to better design and adapt built form for the increasing presence of water.

### 1.4 Glossary of Terms

Technical terms are utilized in this research as follows:

1. **Hard-Infraestructure [for Flood Protection]**
   Strategies adopted in order to protect urban areas from variations in water levels, usually

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\(^5\)“‘soft-infrastructure’ – a collection of multiple and iterative strategies that buffer or absorb flooding” (Bergdoll 2011, 44), which include restoring wetlands and dunes, building streets with pervious pavement, and adopting green roofs to slow down water runoff.
based on the construction of human made barriers. These include: sea walls, embankment walls, and dykes, among others.

2. **Soft-Infrastructure [for Flood Protection]**
Strategies adopted in order to buffer or absorb flooding, usually based on the protection and rehabilitation of local ecosystems. These include: restoring wetlands and dunes, building streets with pervious pavement, and adopting green roofs to slow down water runoff, among others.

3. **Polder**
A portion of low-lying land protected from rising waters by dykes. This strategy has been particularly applied for flood prevention in the Netherlands.

4. **Base Flood Elevation (BFE)**
Height of expected floodwaters determined by local authorities in flood insurance maps.

5. **Design Flood Elevation (DFE)**
Measurement adopted by communities above the Base Flood Elevation that must be followed as a design reference.

6. **Dado**
Lower segment of a wall that differs from its upper portion by the application of different materials and/or methods of construction.

7. **Pontoon**
Air-filled structure bearer of buoyant properties and utilized in the basis of floating structures.

8. **Dry Flood Proofing**
Measures applied in order to prevent floodwaters from entering a structure, defined as perimeter barriers.
9. *Wet Flood Proofing*
Measure adopted to minimize damage, such as the use of water resistant materials, when waters are allowed to enter a structure.

10. *Resilience*
The capacity of a system to withstand outside pressures, moving back to its original condition after the pressures fade away.

11. *Flexible Systems [in relation to flooding]*
Systems capable of changing form, purpose, and/or position, according to external climate conditions.

12. *Static Systems [in relation to flooding]*
Systems that maintain form, purpose, and/or position, regardless of external climate conditions.
CHAPTER 2 RESEARCH OVERVIEW

2.1 Literature Review

Analyzing New Perspectives on Flood Design

“The movement of water along a vertical scale draws attention to the subtle configurations of topography and the consequential horizontal extent of flooding. During a flood, the vertical section gives rise to new formations and understandings of a city. Today, flooding has become synonymous with the impact of global sea level rise, and the threat of rising waters has taken on a new sense of urgency. Studying the planar transformation that takes place during high-water events is an opportunity to reinvent and redesign the twenty-first-century city and consider new notions of urban and ecological development.” (Nordenson and Seavitt 2011, 44)

2.1.1 From Hard- to Soft-Infrastructure:

Critiquing the Hard Edge Between Land and Water

In their introduction to “High Stakes: Soft Infrastructure for the Rising Seas” (2011) Guy Nordenson and Catherine Seavitt describe the relationship between human settlements and their adjacent water bodies using as examples the cities of Rome and Venice. In Rome, the authors describe, the recurrent and extensive flood of the Tiber River led to the construction of embankment walls as part of a major infrastructure project developed between 1876 and 1910. This structure would determine a new relationship between city and water, defining an eternal division between the urban environment and the water level, which was visually and physically depressed, bellow the quota of inhabitation. In Venice, on the other hand, city dwellers still experience the transformation of their buildings and open spaces during each period of high tide, when the water occupies the city’s ground level. Buildings’ ground floors are reprogrammed and plazas are redesigned with the placement of temporary wooden pathways, redefining the daily movement of inhabitants and visitors. While in Rome the population and water bodies remain divided, the first existing without experiencing the interference of the

other, in Venice, the level of the tides determine an active relationship between its population and the lagoon. As Nordenson and Seavitt stress, “during a flood, a city is transformed” (Nordenson and Seavitt 2011, 43), and such transformation has become an intrinsic part of the Venetians’ lives.

The relationship between Venice and its surrounding waters, constantly in motion, is nevertheless expected to change in the near future. The city is preparing for the inauguration of the MOSE project, a seawall defense mechanism composed of 78 mobile barriers, designed to hold the Adriatic Sea’s seasonal high tides, which have shaped the city through the years. Some, however, challenge the effectiveness of the 7.9 billion dollars system (Marshall 2013), arguing that the project initiated in the 1970s and to be completed in 2015, might not be able to withstand current and future sea level rise predictions (Nordenson and Seavitt 2011). Nordenson argues that, “despite our best efforts, the city and the water remain one organism. As the sea rises and the storms intensify, the water will break down the boundary again and again” (Nordenson, Seavitt, and Yarinsky 2010, 10).

Hard-infrastructure developments designed to keep the sea out, such as the embankment of Tiber River in Rome in the 1800s and the recent project MOSE in Venice, are currently the focus of a larger debate against solutions that preclude a healthy relationship between populations and their water bodies (Volner 2013). The replacement of definite concrete barriers for a softer edge, defined by different gradients between water and land, is the argument built by urban and landscape designers. They believe in the opportunities of encouraging the contact between inhabitants and their waterways for the establishment of more welcoming public spaces (Mathur and Cunha 2009; Anderson 2009; Volner 2013). Both designers and environmentalists argue that the creation of such buffer zone could represent the reconstruction of wetlands, assuring the preservation of entire ecosystems (Marshall 2013; Bergdoll 2011; Nordenson, Seavitt, and Yarinsky 2010).

As a response to this debate, cities throughout the world have started to rethink their

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7 The term “hard-infrastructure” is used in this thesis to describe defense mechanisms implemented as barriers to stop rising waters from entering urban settlements, such as sea walls, without absorbing the impact of flooding.
planning initiatives in favor of softer boundaries, such as wetlands, dunes and porous streets, redefining the edge between land and water. According to Anderson, “planners and designers are increasingly working to a different tune, recognizing that a more thoughtful and holistic approach to flood risk can be an opportunity to tear down the walls and create more integrated, livable communities instead” (Anderson 2009, 66).

2.1.2 Making Room for Water:
An Urban Planning Perspective

In the Netherlands, the government approved in 2007 the “Room for the River Programme.” The initiative is comprised by diverse interventions throughout the country, in order to increase the outlet capacity of Dutch rivers from 15,000 to 16,000 cubic meters per second (“Room for the River Programme” 2013). The strategies, to be developed in more than thirty locations, range from dyke relocation to floodplain excavation. The Netherlands has historically built barriers to protect their land from the risk of flooding. Hence the new planning project offers a set of possibilities to establish a new relationship between the populace and its rivers. One of the project’s pivotal points is to “improve the quality of the [river’s] immediate surroundings” (“Room for the River Programme” 2013).

“Room for the River Programme” is comparable to other strategies across the globe. In 2004 a government consultation in the United Kingdom defined a new set of strategies for flood defense entitled “Making Space for Water.” The objective of the British project is “to allow space for water [...], while achieving environmental and social benefits” (“Making Space for Water” 2013). The proposal was followed by the “LifE (Long-term Initiatives for Flood-risk Environments) Project Handbook” (2009), consisting of a catalog in which urban design strategies are outlined in order to assist the development of the country’s flood-prone zones, “investigating the permitting of water into sites in a controlled manner” (Curtis 2009, 29). The set of strategies became part of RIBA’s Climate Change Toolkit Package, published in 2010, which aims at encouraging designers to deal with the challenges brought by climate change and global warming.

8 In Dutch: Ruimte voor de Rivier.
2.1.3 Building a New Edge: 
An Urban and Landscape Design Perspective

Allowing for the presence of water asks designers to rethink how the edge between urban settlements and water bodies should be conceptualized. Sea walls and storm-surge barriers are replaced by a flexible “grade band” (Volner 2013, 51), working as a filter to accommodate the in-and-out movement of the tides (Mathur and Cunha 2009). In the process, “the line between the water and the city is blurred, diffused, thickened. Additional programming and infrastructure stretch out beyond the conventional urban boundary, while at the same time natural elements penetrate it from without” (Volner 2013, 51). In “On the Water: Palisade Bay” (2010), Nordenson, Seavitt and Yarinsky describe how some of these soft edges could take place in the form of interconnected infrastructures and landscape design. Offering a thorough assessment of the challenges posed by rising seas in Upper New York Bay, they divide the area in five zones, describing alternatives for the development of soft and absorptive habitats. These would be created thorough: the implementation of islands and reefs to withstand the impact of storms and establish new habitats; the revitalization of the waterfront, combining tidal marshes, parks, and piers for leisure activities; and the establishment of new zoning ordinances to allow for quick adaptation, improving community resilience to future storms (Nordenson, Seavitt, and Yarinsky 2010). According to the authors, “the proposal implements a series of soft-strategies to alternatively buffer or absorb flooding, creating a new destination on the water” (94), while addressing its fluid presence as an urban condition.

Additional approaches to absorbing landscapes can be found in the literature. In “Design for Flooding” (2011), Watson and Adams present the impact of natural events on human made environments, describing landscape design strategies and building code’s regulations to mediate flooding. In order to slow water down, “swales, reed beds and underground holding tanks; parks, trees and gardens; permeable paving and green roofs” (Anderson 2009, 62) should be applied, creating flexible landscapes able to accommodate water for a longer period in flood-prone environments. The objective is to allow for the presence of water, and hold it as long as possible, before the tide goes back to its original level.
2.1.4 A New Approach to Built Form:  
An Architecture Perspective

Designing for the presence of water is a theme that, although recent, has rapidly consolidated in the literature. Several studies have been conducted trying to understand, categorize and give advice as to how new developments in flood-prone zones should take place, as previously presented. However, exploring mainly the fields of urban and landscape design, none of them provides an in-depth analysis of the implications of environments with changing water levels in architecture.

The challenges of designing to withstand flooding have been tackled by architects throughout the world. In the United Kingdom, the office Baca Architects have proposed the “Amphibious Home” as an alternative to withstand floods from the Thames River. The house sits on a platform located on the top of hollow pontoons, and, whenever the level of water rises, the entire building floats (“Amphibious Home” 2013). In Australia, three levels compose the “New Queenslander,” a house designed by Cox Rayner Architects, each playing a different role in the event of a flood (Rajagopal 2013). In the United States, the “FLOAT House”, designed by Morphosis for a post-Katrina New Orleans, presents a floating building connected to flexible infrastructure and able to prevent the material loss resultant from major flood events (“FLOAT House” 2012).

Solutions vary from preventing property damage, to allowing affected populations to remain in their homes during a flood. The emergent built forms are characterized by a greater flexibility of their elements, generating structures that are raised, buoyant or permeable, offering a range of solutions to cope with the frequent presence of water. Designing to give room for water indicates the establishment of unique architectural proposals, which extend beyond the development of technical solutions. It defines a new type of spatial organization, redefining how inhabitants relate to their surroundings through the arrangement of the different elements that compose built form.

Nonetheless, buildings designed for flood-prone zones often appear in current literature only to exemplify larger urban forms, superficially described in order to portray specific urban patterns for settlements near major water bodies, such as in “Amphibious Housing
in the Netherlands” (Nillesen and Singelenberg 2011). Additionally, architecture for flooding often appears merely listed at the end of flood-prevention catalogs, such as “Facing Up to Rising Sea Levels” and “Climate Change Toolkit 07 Designing for Flood Risk” (RIBA (Royal Institute of British Architects) 2010; Curtis 2009). In the book “Design for Flooding” (2011), Watson and Adams further describe architectural solutions when conveying strategies to prevent material loss in face of flood events. The assessment of architecture is, however, limited to an analysis of United States’ building codes.

Focusing on the study of houses designed for zones prone to flooding, this research fills a gap in current literature, developing a framework for a thorough analysis of architecture and offering suggestions for its development in environments affected by recurrent flood events.

2.2 Research Question

The literature review has shown that there is no systematic analysis of architecture in environments prone to flooding. Hence, the current study focuses on the question: **How can architecture adapt to constantly changing water levels?** The research fulfills the following objectives:

1. To examine new housing typologies and building elements that emerge in flood-prone zones, offering a systematic analysis of architecture and a portfolio of ideas, which can later be combined. This will allow architects to design buildings able to minimize the distress of affected populations, allowing for their permanence in areas prone to flood events, and contributing to the creation of resilient environments better suited to withstand flooding.

2. To encourage a paradigm shift in architecture, from the exclusive implementation of static protective structures toward the design of flexible solutions that allow for the temporary presence of water. These can be developed together with hard-infrastructure projects, providing communities with multiple defensive mechanisms applied at
different scales.

2.3 Methodology

In “Frame and Generic Space,” Bernard Leupen states that:

"One way of gaining insight into the process of designing is by analyzing existing work. Such analyses we designate with the term 'design analysis.' If design is a creative process that produces something that did not exist previously, analysis begins with the outcome of the process and then attempts to get at the underlying ideas and principles." (Leupen 2006, 18)

This thesis is based on the idea sustained by Leupen (Leupen 2006, 9) that “much of the knowledge in architecture is stored in buildings and their design.” Hence, the study focuses on a Multiple Case-Study Analysis, developed in two phases. In the first phase I collected and analyzed contemporary architectural solutions for housing in flood-prone zones, developed both in architectural competitions/exhibitions (Amphibious Living, Netherlands; Flood-proof Houses for the Future, United Kingdom; and Rising Currents, New York City) and in built projects (Make it Right Foundation, New Orleans).

In order to guarantee that the analysis of the different projects could be later compared, a pre-defined categorization, guiding the study of each project, was needed. Such a framework is proposed, for example, in Stewart Brand’s “How Buildings Learn: What Happens After They’re Built” (1994), in which the author specifies the six elements that conform a building: Site, Structure, Skin, Services, Space Plan, and Stuff (Brand 1994, 13). For the purpose of this analysis, the six categories were adopted following Brand’s definition, and were adapted as needed (noted in parenthesis): Site is defined as the project location and its specific lot (to this category was added the access to and from the site from the surrounding neighborhood and city); Structure corresponds to the building’s supporting elements; Skin is determined by the layers that constitute the building’s facades; Services (for clarity substituted with Infrastructure) corresponds to elements that support the building (e.g. electricity, water, sewage systems); Space Plan
(for clarity substituted with *Program*) corresponds to the different functions within the building; and *Stuff* (for clarity substituted with *Furniture*) is defined by the objects that can be relocated within the space. Each design solution was analyzed in accordance to these six components.

To initiate the analysis, each case study was re-drawn both in 2D and 3D, followed by the creation of an exploded view diagram. According to Bernard Leupen in “Design and Analysis” (1997), “drawing the object as though it had been taken apart can bring out the relationship between components or aspects of the design” (19). Hence the exploded view diagram became crucial for the understanding, not only of the individual parts, but also of the relationship among parts and the structure as a whole. The six elements previously enunciated were then analyzed in isolation and in relation to the adjacent parts within the system. This Multiple Case-Study Analysis is presented in Chapters 3 and 4.

In the second phase I compared the data collected, synthesizing it in the form of a matrix (Appendix). Using the matrix, I was able to define which architectural elements become more flexible in buildings designed for flood-prone zones. The study of the different combinations between flexible and static architectural elements signalized alternative forms for human inhabitation of the floodplain. This examination indicated that certain combinations directly relate to concepts of flood resilience, going beyond the creation of structures physically able to withstand flooding. This analysis is presented in Chapter 5 and culminates with a set of principles to be adopted in the design of structures in zones prone to flooding.

Finally, a set of rules defining and/or restricting the implementation of the analyzed design strategies are summarized in Chapter 6 through the examination of the National Flood Insurance Program, in the United States, and the guidance “Improving the Flood Performance of New Buildings: Flood Resilient Construction,” in the United Kingdom. This analysis shows that, when zoning regulations permit residential development in the floodplain, building codes must be adapted to allow for responsive design strategies.
2.4 Scope of the Research and Limitations

Following the need to accommodate an increasing population, altogether with the ubiquity of flood events that currently push the margins of floodplains further inland, the research focuses on residential design and on specific building methods applied to cope with flooding, without assessing particular cultural responses to flooding or aesthetic results. The choice to focus on both built and unbuilt projects, aims at broadening the scope of the research. Built work can unveil the influence, and correspondent adaptation, under the rules defined by current building codes, while buildings developed for competitions/exhibitions can add solutions envisioned without technical and/or economic constrains.

All case studies selected for analysis are examples of contemporary architecture and were chosen because they utilize current technology and building methods, while representing present urban development patterns. They were also selected for their availability in the literature in English. For these and other reasons, not all projects developed for flood-prone environments are part of this examination, but the wide range of projects selected, both in geographical position and scale, adds the variety of proposals that such research entails. The framework developed can certainly be complemented by future research on the topic.
CHAPTER 3 MULTIPLE CASE STUDY ANALYSIS

3.1 Amphibious Living:
Flexible housing in natural areas declared inhabitable, NL

3.1.1 Competition Overview

The Netherlands has historically faced the challenges posed by an environment prone to flooding. Solutions for dealing with the country’s water excess, creating the terra firma required for urban development, repeatedly relied on reconfiguring water bodies (either by filling or draining), reclaiming land from the rivers, and building dykes (Nillesen and Singelenberg 2011). The country presents large areas in which water is more present than land, such as the province of South Holland, which, built upon a marshy ground, is constantly sinking to a lower level (Venhuizen 2001). This process is still largely remediated by spraying sand and driving piles into the soil, a practice that has proven to be expensive and inefficient, unable to stop underground waters from engulfing the land.

The combination of a growing population, with a renewed interest on living closer to nature, and the scarcity of land to build upon without the use of palliative processes to keep it dry, offered the basis for the competition “Amphibious Living: Flexible housing in

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9 The analysis presented in this chapter utilizes as references the book edited by Hans Venhuizen: “Amfibisch Wonen=Amphibious Living” (2001), and the website “www.amfibischwonen.nl.” Prior to each design analysis, a short introduction summarizes each proposal as described in the source material.

10 The Netherlands’ protective system currently includes “1.430 km of river dikes, 1.017km of lake dikes and 690km of coastal dikes and dunes” (Anderson 2009, 55).

11 According to Hanz Venhuizen, subsidizing grounds require constant maintenance: “Gouda [city in the province of South Holland, NL] has roads that are raised year after year, sometimes acquiring a thickness of no less than eight meters in the process” (Venhuizen 2001, 17).
natural areas declared inhabitable,” launched in the year 2000. The concept of an amphibious structure, defined by the New Oxford American Dictionary as “relating to, living in, or suited for both land and water,” was implemented as the competition’s pivotal point. The call for entries asked for proposals that, rather than fighting the presence of water, offered housing solutions “optimally adjusted” (Venhuizen 2001, 17) to the existing ground conditions. The competition aimed at initiating a discourse on architecture for extremely marshy and flood-prone areas, offering a change in mindsets and asking the inhabitants of flood-prone zones to accept a more unpredictable existence in an environment susceptible to constant change (Figure 3-1).

“Amphibious Living” was a two-phase competition. In the first phase, 150 projects were developed without a determined site. These were later organized in three categories: (1) Landscape and Urban Design; (2) Urban and Architectural Design; and (3) Living and Working with Water. Three projects from each category were selected as finalists. In the second phase, different teams from the first phase were combined to develop specific projects for specific sites in Barendrecht, Rotterdam-IJsselmonde and Gouda.

Figure 3-1 Icons indicating the adaptation of daily activities to the recurrent presence of water
Source: “Amfibisch Wonen=Amphibious Living” (2001, 12–13)

12 The competition was organized by the Kunstgebouw, the Foundation of Arts and Culture South Holland, and Foundation Amphibious Living; Architecture Fund, Johan Matser Project Development, and Van Wijnen West.
13 The projects developed in phase one should be applicable to various marshy and flood-prone contexts in the Netherlands.
The teams were formed by professionals from different fields, responsible for outlining concrete plans for implementation during workshops held in each one of the selected sites.

The three projects developed in phase two (Implementations Barendrecht, Rotterdam-IJsselmonde, and Gouda), which will be analyzed in this chapter, were presented on September 29, 2000, at the symposium and exhibition “Amphibious Living”, at Kinderdijk, NL. All the projects submitted and developed during the competition, were later compiled in the catalog “Amfibisch Wonen= Amphibious Living” (2000), published both in Dutch and English.

3.1.2 Case study 1: Implementation Barendrecht

General Information
Project name: Implementation Barendrecht
Location: Barendrecht, South Holland Province, NL
Date designed: 2000
Concept Manager: Lucas Verweij – Schie 2.0
Implementation Manager: Dennis Moet – Bureau Park
Initial Number of Households: 50

Context
The proposal “Implementation Barendrecht” is located on the Zuidpolder (South Polder), south from the city’s urbanized area. The site extends from the River Waal on the east, to the motorway A29 on the west, and the River Oude Maas in the south. The area, mainly composed by farmlands, became habitable after the damming of the
IJseelmonde Island in 1580. Since then, the soil has sunk to a lower level, and the ground, stable at first glance, is now described as “thick water” (Venhuizen 2001, 202). When the “Amphibious Living” competition was first announced, the Zuidpolder was next in line for urban development. The land-use plan indicated “nature, recreation, housing, and businesses” (Venhuizen 2001, 200) as potential uses for the area.

Proposal Overview

*Master plan*

![Figure 3-2 Implementation Barendrecht, Masterplan Source: “Amfibisch Wonen=Amphibious Living” (2001, 206)](image)

The team envisioned an area for light urbanization, to be developed as an ‘Amphibious Zone’ for residential and recreational purposes. The idea was to diminish the use of current infrastructure keeping the area dry, planning for the pumps to be activated only when the water reached a predetermined maximum (1 meter above average ground level).

The master plan developed for the ‘Amphibious Zone’ was based on the concept of

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14 By the time of the competition, recent developments in nearby ground had to be restructured with new pile foundation after their sewage system sank into the ground because of the forces exerted by its own weight. (Amphibious Living)
'timescaping', focusing on the occupation of the site over time through the combination of light urbanization and natural landscape. The entire scheme was designed to change according to different seasons and their periods of inundation. The site was thus approached as both temporarily dry and temporarily wet.

**Housing Units**

The team proposed three types of housing units: “water dwellings” (movable), “amphibious units” (semi-permanent), and fixed “light weight dwellings” (permanent). Emphasis was given to the “Amphibious Unit”, highly self-sufficient and autonomous, which would sustain one position while the polder was dry and move freely during the period of high tides. According to the designers, acquiring an amphibious unit would ask the inhabitant to adapt to an amphibious existence, unbound by traditional provision of infrastructure (Venhuizen 2001).

**Design Analysis: Amphibious Unit**

*Section and Floor Plans to scale*

Figure 3-3 Implementation Barendrecht, Section of the house in a dry condition (top), followed by a Section of the house during a flood (bottom)

Source: Karen Paiva Henrique
Figure 3-4 Implementation Barendrecht, Garden Roof Plan (top), First Floor Plan (bottom)
Source: Karen Paiva Henrique
Exploded 3D Diagram

AMPHIBIOUS UNIT
Barendrecht, NL

INFRASTRUCTURE
Water/ Solar Power Collection System

PROGRAM
Green Roof

STRUCTURE
Floating Base

SKIN
Outer Shutters

Figure 3-5 Amphibious Unit, Exploded Perspective
Source: Karen Paiva Henrique
Site
Plots are not defined, but studies were made determining different scenarios for the future occupation of the polder (Figure 3-6). The homes are detached from their original positions and, when the high tide comes, they float freely, constantly shifting their place within the polder. Residents will access their houses through floating paths (wet season) and existing roads (dry season). In this proposed arrangement, the relationship between site and house becomes more fluid. The building is conceived as one of the elements of an always-evolving landscape.

Figure 3-6 Implementation Barendrecht, Density Studies
Source: “Amfibisch Wonen=Amphibious Living” (2001, 217)
**Structure**
The unrestrained relationship between site and building defines its structural elements. The building rests on a floating platform completely detached from the ground, which allows dwellers to move their houses during the high tide, positioning it closer to other structures. Special mechanisms to allow for this mobility are not specified.

The act of repositioning the house reflects upon the relationship between dwellers and their neighbors, potentially strengthening community bonds (one can choose to relocate his/her house closer to friends). Furthermore, the act of moving the building between seasons can improve the connection between inhabitants and nature. The polder's new inhabitants become constantly aware of the natural processes of their environment, by moving their dwelling within an always evolving landscape.

Above the floating base, the house consists of a pre-fabricated unit, offered in a catalog of parts that can be assembled according to the user’s preference. The primary structure of the building defines a framework within which facade components and inner partitions can be arranged in various ways. Two sets of secondary structures are attached to the building’s primary structure and support a double facade system.

**Program**
The two facades are set 1 meter apart, providing enough room for users to occupy the space. This area, which could be interpreted as a traditional porch, defines a crucial buffer zone, providing the residents with privacy when different dwellings drift closer together during the high tide.

The house is covered by a green roof, which acquires the function of ‘back yard’, guaranteeing a dry open area for the house’s occupants even when the polder is flooded.

**Skin**
The structure’s double facade system defines both the connection between man and nature, and the residents’ privacy. The outer skin offers a dynamic exterior through a set of shutters that can be completely opened, enhancing the connection between man and water. At the same time, the inner skin encloses the interior space, adopting a more conventional facade made of opaque panels and glass.
Lightweight materials (osiers, bamboo, clay, hemp, and coconut fiber) are used on both facades, maintaining the house’s floating properties.

**Infrastructure**
In order to float freely, the house is conceived as a self-sufficient unit in terms of energy, water, and sewage collection. Energy is harvested from the sun and stored into a battery system. Water is collected from the rain and filtered on the roof garden to be later used in the toilet and in the shower (which would require additional filtering devices). The sewage is treated in a composting station located inside the house.

**Policy**
Since the building floats freely, without a defined plot, the entire polder is not set in terms of individual property. Permits for moorings would be issued, ensuring the limitation of the number of units occupying the area.

**Significance and uniqueness of the project**
The proposal achieves environmental and economical sustainability, reducing energy consumption at the master plan level (the pumps are no longer kept constantly functioning in order to keep the entire area dry), at the same time minimizing the inhabitants’ dependency on fossil fuels, providing a more self-sufficient existence.

At the same time, the project allows housing developments to take place on one of the city’s prime areas, even if faced by recurrent floods. The project creates a stronger connection between city inhabitants and the river, bringing the margins of urban development closer to water.

**Limitations**
At the same time that the project offers freedom of location, creating an interesting and always-changing landscape, the new take on property can potentially lead to conflicts (e.g. who would have the right to occupy a specific portion of the polder).

The process of building homes from a catalog could also pose as problem, restricting individual options and leading to the establishment of a monotonous neighborhood.
The lack of a more detailed proposition for the floating paths, connecting individual amphibious units to the existing roads, restricts the accessibility of the houses to individual boats. Even if guaranteeing higher privacy to the inhabitants, such restriction on access limits the connection of the amphibious units to the surrounding city during the high tide.

The proposal also fails to explain which type of foundations will be used to stop houses from sinking into the marshy grounds during the dry season, and how these foundations would be applied without limiting the owners freedom to move the houses within the polder.

**General features and lessons**

The design of the Barendrecht’s “Amphibious Units” applies several concepts that can be further developed and replicated in other sites. The unit is self-sufficient in terms of energy, water, and sewage treatment. This guarantees not only a built environment that can constantly change together with its landscape, but also instigates a change in mindsets, lessening the human dependency on non-renewable natural resources.

Moreover, the project reflects on ideas of freedom and privacy, pushing the boundaries of property lines and creating a free object that relates to its surroundings, while maintaining the privacy of its users.

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3.1.3 Case study 2: Implementation Rotterdam–IJsselmonde

**General Information**

Project name: Implementation Rotterdam–IJsselmonde  
Location: Rotterdam-IJsselmonde, South Holland Province, Netherlands  
Date designed: 2000  
Concept Manager: Henk de Vroom – Bureau de Vroom  
Implementation Manager: Juliette van der Meijden – Bureau B+B  
Participants of the Workshop: (1) Krijn Giezen - kunstenaar (2) Oscar Rommens and Joris van Reusel – Import – Export Architecture (3) Toshikazu Ishida – KID (Kyushu
Context

The proposal “Implementation Rotterdam-IJsselmonde” focused on four different areas of IJsselmonde, NL: (1) the central borough park, (2) the polder between IJsselmonde and Beverwaard, (3) the botanic garden, and (4) the harbor. The first three locations don’t posses direct accesses to water, but their soil is as marshy as in other parts of the Netherlands. The soil is kept dry through a system of pumps and the structures built in the area rest on piles deeply carved into the earth, subsidizing at uneven rates.

The proposal defies the common assumption that IJsselmonde rests on solid ground, assuming its soil as a layer floating on water. The design team approached the four sites, physically separated within the township, as part of one ‘aquatic’ landscape. The main concept behind the project was to recreate the water connections between these four areas, which were lost through the development of IJsselmonde, inviting the Nieuwe Maas River back into the heart of the city.

Proposal Overview

Master Plan

The proposal is built upon the idea that the different water bodies that permeate IJsselmonde (canals, ditches, and ponds) should be interconnected in one system, with the water level varying according to season (Figure 3-7). The waterways connecting the system would be navigable, providing the possibility for built structures to freely navigate within the city. Together with the idea of floating homes, the team proposed a set of floating structures such as “an amphibious botanical garden, and a multifunctional platform” (Venhuizen 2001, 229).
Housing Units
The team proposed three different housing options: (1) “Amphibious Houses” built at the local Cultural Landing Factory (the former ship yard would be converted into a factory for amphibious housing production); (2) the “Split-Level House”, which was divided in a fixed autonomous unit connected to a mobile floating section, and (3) the “Floating Flop”, a set of floating modules, connected by floating pathways.

Design Analysis: Floating Flop
The “Floating Flop” strategy envisioned an interchangeable floor plan, composed by a set of smaller cells that could be arranged in diverse ways (Figure 3-8). The team conceived a structure that would always be located above the water level, regardless of low or high tides. Following this concept, the building functions independently from variations on the water level.

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15 From all housing types proposed, the Floating Flop, developed during the first phase of the competition, will be analyzed as a case study because of the proposal’s level of detail.
Three cells compose the “Floating Flop” neighborhood: (1) living container, (2) ecological water garden, and (3) an amphibious open space. Floating pathways connect the different cells, while the flexibility of the form allows for the three units to be combined in different ways. Parking spaces are also provided inside the ‘floating’ neighborhood.

Figure 3-8 Floating Flop Neighborhood, Physical Model
Source: “Amfibisch Wonen=Amphibious Living” (2001, 104)
Section and Floor Plans to scale

Figure 3-9 Floating Flop Cell, Section
Source: Karen Paiva Henrique, adapted from “Amfibisch Wonen=Amphibious Living” (2001, 103)

Figure 3-10 Floating Flop Floor Plan, Module (left) and Neighborhood (right)
Source: Karen Paiva Henrique, adapted from “Amfibisch Wonen=Amphibious Living” (2001, 103)
Exploded 3D Diagram – Floating Cell

FLOATING FLOP
Rotterdam-IJsselmonde, NL

STRUCTURE
‘U’-Shape Shell
Floating Base

PROGRAM
Floating Living Container

SKIN
Variable Materials/Opacity

INFRASTRUCTURE
Traditional Systems
Embedded on Pathways

Figure 3-11 Floating Flop’s Cell, Exploded Perspective
Source: Karen Paiva Henrique
Site
The combination of housing cells forms a dwelling, while the combination of these with landscape cells gives shape to the neighborhood. While the houses rise and fall following the movement of the tides, as in the previous case study, the houses designed for IJsselmonde are anchored in place. This enables a better definition of property lines and a defined access to the houses.

Structure
Each individual cell rests on a floating base and is structured by a “U” shape shell, which is composed by the cell’s roof and two of its walls (shorter in width). This composition gives a higher freedom to the materiality of the two remaining walls, creating more fluid floor plans for the individual houses.

The pathways connecting the houses present a structure independent from the cells in terms of loads, but are attached to their bases, providing access to the different parts of the neighborhood.

Program
The floating living containers (2.5 x 6 meters) possess different functions: “meeting, cooking, sleeping, bathing, dinning, playing, storing, and relaxing” (Venhuizen 2001, 103). The number of cells utilized in a home varies according to the composition of each house, and their correspondent size. Individual homes present cells with openings to the water below, establishing a direct contact between inhabitant and water.

Green roofs located on each cell provide a living space for birds and insects, allowing for the creation of an entire ecosystem that could not be exist in this location otherwise (the green roofs provide a ‘dry’ environment within the marshy polder throughout the year).

Skin
Each cell’s skin varies in accordance to the privacy required by its function and its distance to neighboring houses. The skin’s material ranges from an opaque panel, to a glass and finally to a completely open arrangement. Variations between the three are proposed in conceptual models (Figure 3-8), but are not fully detailed.
**Infrastructure**

The floating pathways connecting the different units support the lines that provide energy, water, and sewage collection for the individual homes. Each house possesses a water-filtering tank, while public water gardens spread across the neighborhood contain vegetation responsible for purifying the water of the polder.

**Policy**

The proximity and materiality of the cells between neighboring houses would have to be adjusted according to safety regulations (e.g. fire codes), assuring the security of the complex.

The neighborhood model and the proximity of the houses creates a higher sense of community living, which can certainly be used in favor of maintaining the complex as a whole.

**Significance and uniqueness of the project**

The project redefines the idea of a traditional city block in an amphibious zone, combining units through the use of shared walls. The “Floating Flop” solution offers at the same time spacious individual dwellings and a compact neighborhood.

Water is an integral element of the proposal. Water treatment features are offered both at the unit and neighborhood level, maintaining a healthy environment for the polder. Inside the units, openings to below create small natural ponds that work as a constant remainder of the environment in which the houses are situated.

**Limitations**

The project is still highly dependent on traditional sources of infrastructure and the level of privacy within cells might be considered a problem for inhabitants accustomed to more traditional settings.

**General features and lessons**

The project offers a combination of traditional elements (infrastructure provision and parking spots close to the units), with a more flexible arrangement (amphibious homes and floating pathways), a model that could be more easily applied in a real setting. The
“Floating Flop” offers a less drastic approach for amphibious living, without asking the dwellers to completely alter their life-styles in order to adapt to the changing conditions of a flood-prone site.

3.1.4 Case study 3: Implementation Gouda

General Information
Project name: Implementation Gouda
Location: Gouda, South Holland Province, Netherlands
Date designed/planned: 2000
Size: 72 hectares
Concept Managers: Mark Mantingh and Mark van Steenbergen, students OK5/Beeldende kunst en de publieke ruimte, Arnhem
Implementation Manager: Michiel Parqui, Student Bouwkunde TU Delft
Participants of the Workshop: (1) Dennis Martens – Cees-Jan de Rooi, Arnhem (2) Joop Schaghen – Bureau Oranjewoud BV, Rotterdam (3) Sander van Veen, Amsterdam (4) Paul Kuipers, student Arnhem (5) Nick Nguyen, Student Arnhem

Context/ Site Analysis
The Oostpolder (East polder), a region surrounded by water, is located west from Gouda’s city center. Its soil is considered one of the marshiest in the Netherlands, with the polder resting 2.5 to 2.8 meters below the Normal Amsterdam Level (NAP). Part of the Groene Hart (Green Hart), the Oostpolder cannot be developed for traditional housing.

Program elements
Master Plan
In face of such conditions, Implementation Gouda aims at allowing water in, developing Gouda as a reservoir. The idea is to utilize the polder as an outlet for the Gouwe River’s water excess, solving other regions’ overflow problems. The proposal outlines that the Oostpolder could also be used as a reservoir of fresh water to be consumed in other parts of the city (Figure 3-12).
Figure 3-12 Implementation Gouda, Masterplan
Source: “Amfibisch Wonen=Amphibious Living” (2001, 104)
Housing Unit
The team adopts amphibious dwellings as an alternative for the area’s development, especially because, as stated by the designers, these are not documented as real estate in the Netherlands.

According to the proposal, the polder’s new dwellers would embrace nature as the element responsible for shaping their surroundings, rather than controlling the area to suit a more traditional urbanization. The proposal asked for a change in lifestyle, in which the inhabitant of an amphibious house would adopt an ‘amphibious life-style’. The team stated:

“Sometimes the dwelling will float; sometimes the ground will be dry; sometimes a tractor (or a hovercraft) is the only vehicle to transport you over the marshy ground. In exchange for such inconveniences, the residents have a unique and constantly changing living environment, a strong relationship with nature and numerous possibilities for change” (Venhuizen 2001, 255).

Design Analysis: Floating Module

Section and Floor Plans to scale

Figure 3-13 Implementation Gouda, Section of the house in a dry condition (top), followed by a Section of the house during a flood (bottom)
Source: Karen Paiva Henrique
Figure 3-14 Floating Module, Floor Plans
Source: Karen Paiva Henrique, adapted from “Amfibisch Wonen=Amphibious Living” (2001, 103)
FLOATING MODULE
Gouda, NL

INFRASTRUCTURE
Solar Panels

SKIN
Operable Walls/
Skylights

PROGRAM
Floating Module

STRUCTURE
Floating Base

Figure 3-15 Floating Module, Exploded Perspective
Source: Karen Paiva Henrique
Site

The inhabitants would have the option to choose where to locate their dwellings within the polder. Similar to “Implementation Barendrecht”, there is no defined site for each house and the entire polder is open for the relocation of the houses in different seasons.

The proposal, however, goes beyond “Implementation Barendrecht” in terms of property location. It envisions that, in the future, when amphibious developments become ubiquitous in the Netherlands, one’s house could be lifted above the dyke with the assistance of a crane, navigating via the Gouwe River to a new location within the city. In addition, the master plan presented a parking lot located next to the dyke, with the possibility for homeowners to choose to be closer to their vehicles.

In order to guarantee a reasonable occupation of the polder, the number of units is limited to 2700, restricting occupation to a maximum ratio of 15 percent of living space to 85 percent of open space (Venhuizen 2001, 261). Units are to be kept 10 meters apart, unless otherwise allowed by the contiguous unit occupier. Mechanisms for the control of the distance between units are not specified.

Access roads and floating pathways are not included on the proposal. The designers add that it is expected for the inhabitant to find creative ways of reaching the housing unit, either by tractor (Venhuizen 2001, 255) (when the polder is dry), or by boat or amphibious vehicle (259) (when the polder is flooded).

Structure

When the water level rises, the house rises, when the water level drops, the house rests again on the marshy soil of the polder. The amphibious dwellings consist of prefabricated 40 square meters “floating modules” that can be arranged in accordance to the dwellers’ needs. Each module is divided in four parts, with the enclosing walls of two diagonal parts functioning as the primary structure, and allowing for a more ‘open’ arrangement in the module’s remaining walls. The house’s materials and structural components are not specified.
Program
The house’s program is distributed in several modules, varying in accordance to the owner’s needs. Modules can be added or subtracted, guaranteeing the flexibility of the housing units through time.

Skin
In the two structural corners, the house’s skin is more opaque and static, while in the remaining non-structural sections the walls and the roof are composed by mobile partitions. These can be opened according to season, regulating the contact between the dwellers and their surrounding environments.

During the summer walls and roof open, maximizing ventilation and the house’s outdoor space, while in the winter the structure becomes more enclosed, maximizing the indoor living area. With this strategy, the houses’ unused spaces, a consequence of extreme weather conditions, are minimized.

Infrastructure
The house is designed to be entirely independent from traditional infrastructure, from access roads, to the provision of water and electricity. The proposal however doesn’t specify how such infrastructural freedom could be achieved, especially in terms of the provision of utilities.16

Policy
The houses are originally conceived as non-real state property. Hence the inexistence of a defined site doesn’t pose as problem. Each house is to be legally approached as a boat, able to navigate freely within the polder.

Significance and uniqueness of the project
In terms of its master plan the proposal is unique, offering a solution to solve flood problems in other parts of Gouda, at the same time functioning as a fresh-water reservoir for the entire city.

16 The physical model, presented with the proposal, only indicates the use of solar panels on the roof.
Regarding the housing unit, the possibility of adding or reducing the number of modules certainly provides a longer lifespan for the project, which can be adapted according to the needs of future users. The proposition of working with modules is inventive and can be further developed. Different modules could, for example, be added among different houses creating ‘floating plazas’ in the neighborhood.

Furthermore, the houses’ response to weather conditions establishes a dynamic structure that can easily adapt to different seasons and climates.

Limitations
The project doesn’t offer much detail, losing the opportunity to create a more realistic case for implementation. Materials, structure, and infrastructure represent some of the elements addressed by the team only superficially. The inhabitants’ privacy when the units become closer is another aspect not addressed by the proposal.

General features and lessons
The idea of creating a reservoir with the development of amphibious homes is extremely valuable and can certainly be applied in other places suffering from floods. The concept of a house that adapts to climate variations can provide insights for more sustainable approaches in terms of heat gain and loss, and energy consumption, intensifying the relationship between inhabitants and their surrounding natural environment.
3.2 Norwich Union competition: Flood-proof houses for the future, UK

3.2.1 Project Overview

In the book “Homes for a Changing Climate”, Will Anderson describes the long term relationship between the United Kingdom’s inhabitants and their surrounding water bodies: “The British population has a long tradition of messing about in boats and enjoying the pleasures of rivers, canals and the seaside” (Anderson 2009, 24). The author points to the fact that, different from other countries developed near water, homes built in the UK “open up to the river and celebrate the light and life of the water” (59), rather than sheltering behind protective structures.

In 2007 extreme rainfall leading to extended periods of flooding challenged such traditional British developments. New guidelines for construction in flood-prone zones were outlined, defining high-risk areas in which new constructions shouldn’t take place. The delimitation of such areas remains, however, constantly challenged by future climate scenarios in Britain, which predict an increase in winter rainfall between 20 and 40 percent by 2040, and 50 percent by 2080 (Anderson 2009).

The uncertainties facing UK’s future climate, combined with the government’s plan to build three million new homes by 2020 (which in face of the already limited land in the UK will potentially be located on floodplains), set the grounds for the “Norwich Union competition: Flood-proof houses for the future,” launched in 2008 by the Norwich Union Foundation together with the Royal Institute of British Architects (RIBA).

The competition, which received a total of 85 proposals from around the globe, didn’t specify a site, but defined that each house should be designed with 150 square meters,

17 The analysis presented in this chapter utilizes as references the booklet “Flood-proof houses for the future: A compendium of design (2008) and the article “Water Level-fighting Houses” (2009). Prior to each design analysis, a short introduction summarizes each proposal as described in the source material.

18 Under low emission scenarios.
and be situated on a 270 square meter plot. Proposals should consider a designed flood elevation\textsuperscript{19} of 0.6 meters, and follow current building regulations.\textsuperscript{20} The design should focus on innovative and insurable housing solutions for flood-prone areas, guaranteeing the safety of the population and minimizing damage to the house and to the occupants’ possessions (Norwich Union and Royal Institute of British Architects 2008a).

Four winning proposals, to be analyzed in this chapter, were selected by the jury and, together with other selected projects, were published in the booklet “Flood-proof houses for the future: A compendium of design” in 2008.

\subsection*{3.2.2 Case Study 4: Turnaround House}

\textbf{General Information}

\textbf{Project name:} Turnaround House  
\textbf{Location:} Flood plain, UK  
\textbf{Date designed:} 2008  
\textbf{Size:} Single-family house 150 m\textsuperscript{2}, plot 270m\textsuperscript{2}  
\textbf{Team:} Nissen Adams LLP (based in London, UK)  
\textbf{Consultants:} Mendick Waring Ltd

\textbf{Proposal Overview}

The “Turnaround House” proposes a flexible two-story home, able to adapt in face of a flood by allowing the water to infiltrate its first floor. When the water rises, inhabitants are allowed to stay inside the house, which remains physically connected to the surrounding neighborhood and to the provision of utilities.

\textsuperscript{19} Design Flood Elevation (DFE) is the measurement adopted by communities above the Base Flood Elevation (BFE) that must be followed as a design reference. In the US, the DFE usually extends 1 foot above the BFE (Watson and Adams 2011).

Design analysis: the Turnaround House

Section and Floor Plans to scale

Figure 3-16 Turnaround House, Section of the house in a dry condition (top), followed by a Section of the house during a flood of 0.6 meters (bottom)

Source: Karen Paiva Henrique, adapted from “Water Level-fighting Houses” (2009, 103)
Figure 3-17 Turnaround House, Second Floor Plan (top), First Floor Plan during a flood (bottom)
Source: Karen Paiva Henrique, adapted from “Water Level-fighting Houses” (2009, 103)
Exploded 3D Diagram

**TURNAROUND HOUSE**
Floodplain, UK

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**FURNITURE**
- Grand Storage Wall

**SKIN**
- Variable Materials adopted according to proximity with water

**INFRASTRUCTURE**
- Water Storage System

**PROGRAM**
- Relocation of Activities to the Upper Floor during a flood

**STRUCTURE**
- Concrete Dado

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Figure 3-18 Turnaround House, Exploded Perspective
Source: Karen Paiva Henrique
Site
The project assumes a maximum flood elevation of 0.6 meters, during which the property won’t be damaged. The house’s main structure is static, while a floating concrete pontoon located outside the main structure rises together with the water in order to protect the family’s car.

The site is surrounded by gabion walls, which prevent the entrance from debris into the housing property. The house also presents an elevated garden built adjacent to its main facade, guaranteeing its occupants access to an open green space during of a flood. Such gardens are connected by timber shutters located on the second-floor, which fold down during the flood, creating a continuous raised path between neighboring structures.

It is envisioned that such paths could connect the houses to other neighborhood amenities, allowing for the dwellers’ daily-lives to continue without any disturbance before, during and after a flood.

Structure
The house presents a traditional structure, composed by a concrete foundation and prefabricated insulated walls. The concrete foundations extend beyond the slab on the ground floor, creating a 1 meters high concrete dado, which provides resistance and easy maintenance of the structure during and after a flood.

Skin
Besides the concrete dado, concrete flooring is adopted on the ground floor for durability and maintenance purposes. The staircase's materials are also chosen in accordance to their durability when confronted to the recurrent presence of water. Up to the flood line, the stairs are made of concrete, while above this line the materials change to wood, allowing for the location of storage compartments in each step. Besides fulfilling durability purposes, the difference of material adopted on the stairs serves as a constant reminder of the transient environment in which the house is located. On the roof, operable skylights are designed to expedite the process of drying the interior of the house after the flood.
**Infrastructure**
All electrical components (wires and outlets) are located above the flood line. Water provision is kept through the following measures: potable water is stored on compartments located on the second floor slab, and a water tank located above the bathrooms maintains the toilets’ flushing capacity. Such design strategies allow the continuous provision of utilities to the house.

The structure presents an open space underneath the ground floor, which allows for low floodwaters to flow under the structure without entering the house’s livable space or causing any disturbance to the inhabitants. This space also serves for drainage purposes after a flood, directing the water to exit the house on its rear portion.

**Program**
The house is designed with activities on both floors (bedrooms on the first floor and social spaces on the second floor), but, when the flood warning is issued, the occupation of the house changes and all activities of the ground floor are relocated on the structure’s upper level. The kitchen is originally situated on the second floor, safeguarding appliances.

It is interesting to notice that the house presents two lobby spaces (in the first and second floors), in order to connect both to the street, located at the ground level, in normal climate conditions, and to the elevated pathway during a flood.

**Furniture**
The “Turnaround House” is the only competition proposal analyzed that utilizes furniture as a design component when offering an alternative for houses in flood-prone areas. In order to protect personal belongings from damage, several storage spaces are designed throughout the house (inside the second floor slab, and within the steps of the staircase). The house’s central wall is planned as a grand storage wall, with fold out tables, shelves, and diverse storage compartments ranging in scale.

When confronted by flooding, residents often raise their personal belongings in order to protect them from direct contact with the water. The “Turnaround House’s” furniture
design allows dwellers to protect small and large objects from the contact with water in an organized manner.

**Policy**
The competition sought proposals that would comply with current building codes and governmental guidelines for construction in flood-prone zones in the United Kingdom, offering the possibility of the homes to be fully insured. Therefore the “Turnaround House” doesn’t challenge local policies as the case studies previously analyzed.²¹

**Significance and uniqueness of the project**
The “Turnaround House” offers a feasible strategy that can be easily implemented, both in financial and construction terms. It doesn’t present any high-tech solution new to the market that could exponentially elevate construction costs. On the contrary, it reinterprets common design strategies in an inventive way, allowing for inhabitants and floodwaters to coexist inside the house.

**Limitations**
The design doesn’t seem to account for the house’s inner temperature, which can drop substantially once water occupies the ground level. It would be probably necessary to propose a way of isolating the second floor in order to guarantee its habitability during a prolonged flood.

**General features and lessons**
Rather then sealing off its interior from the surrounding waters, the “Turnaround House” offers a strategy to incorporate water as a design element. The entire house is designed for the maintenance and protection of personal property from water damage through an intricate storage system, at the same time guaranteeing continuity to its occupants’ daily-lives regardless of flooding.

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²¹ The same applies for the three additional Norwich Union Competition proposals analyzed in this chapter.
3.2.3 Case Study 5: Eleena Jamil Architects’ House

General Information

Project name: Eleena Jamil Architects’ House
Location: Flood plain, UK
Date designed/planned: 2008
Size: Single-family house 150 m², plot 270m²
Team: Eleena Jamil Architects (based in Malaysia)

Program elements

Master Plan
The project contemplates a solution for housing in flood-prone zones at three different scales: the house, the street and the neighborhood block. The proposal offers a master plan based on Sustainable Urban Drainage Systems (SUDS), with streets designed to retain and direct excess water, minimizing water run-off. Permeable surfaces are designed to replace streets covered with asphalt, generating open green spaces for the community.

Flood Resistant Single-Family Dwelling
Water is kept outside the house up to 0.3 meters, entering half of the structure after reaching this limit. The houses are connected to each other in the neighborhood. Additionally, each individual house presents a system of green spaces responsible for retaining rain water as long as possible before releasing it back to the system.
Figure 3-19 Eleena Jamil Architects’ House, Section of the house in a dry condition (top), followed by a Section of the house during a flood of 0.6 meters (bottom)
Source: Karen Paiva Henrique
Figure 3-20 Eleena Jamil Architects’ House, Model Homes 1 and 2, First Floor plan during a flood
Source: Karen Paiva Henrique, adapted from “Water Level-fighting Houses” (2009, 101)

Figure 3-21 Eleena Jamil Architects’ House, Model Homes 1 and 2, Second Floor plan
Source: Karen Paiva Henrique, adapted from “Water Level-fighting Houses” (2009, 101)

The third floor plan for this project, represented in Figure 3-19, is not available.
Exploded 3D Diagram

ELEENA JAMIL ARCHITECTS’ HOUSE
Floodplain, UK

Figure 3-22 Eleena Jamil Architects’ House, Exploded Perspective
Source: Karen Paiva Henrique
Site
The ground floor of each house is designed in a split-level arrangement made possible through a cut and fill intervention on the terrain. The front part of the house sits on a 0.3-meter high plateau, while its rear part is located 1.2 meters above street level. Following this design strategy, only half of the house’s inhabitable space would be submerged in the event of a flood.

In terms of accessibility, the houses are organized back to back and the connection of the different backyards creates an elevated pathway for egress and rescue.

Structure
The house presents a traditional brick structure. A few modifications are made to assure its resistance to water, such as the adoption of engineered brick foundation.

Skin
Raised door thresholds are adopted in order to prevent water from entering the house below the predefined 0.3 meters limit, providing time for the inhabitants to protect their belongings before the water reaches higher levels. In sections of the house where water is allowed to enter, resilient materials are adopted, such as ceramic tile floors, and “closed-cell board type” insulation (Norwich Union and Royal Institute of British Architects 2008b, 9).

Infrastructure
The design focuses on water management and accessibility in the event of a flood. In order to minimize water run-off, the neighborhood is organized through a series of permeable surfaces and swales, located along the front of the houses, which are connected to local basins and retention ponds. Each house also presents a courtyard, a series of roof gardens, a backyard, and a water-harvesting system, applied toward the same objective as the master plan.

Program
In order to allow half of the ground floor to be submerged during a flood, “Eleena Jamil Architects’ House” presents a specific program arrangement. One of the bedrooms,
probably dedicated to guests, is located next to the house’s entrance. In order to safeguard electrical equipment, the kitchen is located at the higher portion of the ground floor, together with the living room, which possess direct access to the courtyard.

On the second floor, the house (Model Home 1) presents another set of bedrooms: one master bedroom, connected to a more private open green space, and a set of single bedrooms, this time connected to the outdoor patio that leads to the elevated pathway. This open space duplicates the traditional connection between a house and its neighborhood (located at the street level), providing an open green space that works both as front and backyard throughout the year.

*Significance and uniqueness of the project*

The house designed by Eleena Jamil Architects focuses on a plan that goes beyond the single-family house, offering a proposal for a complete neighborhood. The connection among houses is duplicated by accesses located on the first and second floors, which can certainly enhance a sense of community. The neighborhood is designed through an ingenious play of topography and elevated gardens, slowing down the water run-off and directing the water excess toward a collecting system. This generates a variety of open spaces with different levels of privacy (a courtyard on the ground level partially connected to the street, an elevated backyard connected to a neighborhood pedestrian passage way, and a private roof garden accessible only from the master bedroom).

*Limitations*

The overall design delineates a solution to prevent property loss, creating an alternative escape route for the inhabitants in the event of a flood. The project's capacity to provide continued daily-lives during a flood is, however, still underdeveloped.

The project offers several avenues to be further explored in order to achieve undisturbed living. The passageways created among the houses could be easily extended to other neighborhood amenities. Such strategy would allow inhabitants to remain in their houses during the flood, while connected to other parts of the city.
General features and lessons

The proposal builds a strong argument for the development of master plans rather than single architecture solutions for flood-prone zones. It offers the possibility for a more systematic approach that can be certainly adopted by future projects. The intricate design of levels, delineating indoor and outdoor spaces, provides a unique solution that becomes even more interesting when the level of water starts to rise. For example, the master bedroom (Model Home 1) becomes a ‘suspended room’ floating above water during a flood.

3.2.4 Case Study 6: Pohkit Goh's House

General Information

Project name: Pohkit Goh’s House
Location: Flood plain, UK
Date designed/planned: 2008
Size: Single-family house 150 m², plot 270m²
Team: Pohkit Goh (based in Edinburgh, Scotland)

Proposal Overview

Two main elements compose “Pohkit Goh’s House”: a heavy concrete base and a light glass box, covered with wooden vertical elements. The structure is surrounded by a series of landscape components (e.g. “pedestrian path, cycle route, water features, attenuation features, and planted swales”), creating what the architects define as a “green-zone” (Norwich Union and Royal Institute of British Architects 2008b, 11).

The project’s main premises are the establishment of a rich natural environment and a durable built structure. The various landscape elements serve to enrich the site’s biodiversity while the house remains protected against floodwaters through the combination of the site’s topography and a dry ‘flood proof’ ground floor.

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23 Dry flood proofing refers to structures that don’t allow floodwaters inside the structure (Watson and Adams 2011).
Design Analysis

Section and Floor Plans to scale

Figure 3-23 Pohkit Goh’s House, Section of the house in a dry condition (top), followed by a Section of the house during a flood of 0.6 meters (bottom)

Source: Karen Paiva Henrique
Figure 3-24 Pohkit Goh’s House, First Floor Plan during a flood (left), and Second Floor Plan (right)
Source: Karen Paiva Henrique, adapted from “Water Level-fighting Houses” (2009, 99)
POHKIT GOH’S HOUSE
Floodplain, UK

Exploded 3D Diagram

Figure 3-25 Pohkit Goh’s House, Exploded Perspective
Source: Karen Paiva Henrique
Site
The house is designed to keep water out in the event of a flood. In order to achieve this, one of the strategies used is the manipulation of the site’s topography. The house rests on a plateau elevated from the street level, protecting the house from minor floods.

Design elements from the house, such as the walls alignments, extend to the site, giving form to gardens and planted swales that control water flows.

During a flood, the house becomes inaccessible. The house offers an alternative for property safety, but it doesn’t allow for the permanence of inhabitants within their homes during the event.

Structure
The house’s ground floor is made of white finished concrete, a material highly resistant to water, therefore guaranteeing its durability. As stated by the architects, the design intends to “stand the test of time” (Norwich Union and Royal Institute of British Architects 2008b, 11). This concrete ‘base’ acts as a flood defense mechanism, protecting the house’s interior from rising waters.

Skin
While concrete walls define the ground floor, the second floor possesses a much lighter appearance. The house’s upper level consists of a glass box covered with vertical wooden elements. The dimensions and frequency of these elements vary in accordance to the level of privacy and desired contact with nature defined by the activities taking place inside the house. The wood elements also stand as a sustainable feature, controlling the solar gain inside the structure.

Infrastructure
No strategies are described to protect the provision of infrastructure to the house in the event of a flood. Therefore it is assumed that the house relies on traditional infrastructure provision.
Program
The definition of different topographic levels in the terrain creates open spaces located above the street level, guaranteeing a higher privacy for the house’s dwellers when located outdoors.

Significance and uniqueness of the project
The Pohkit Goh’s house proposes a varied landscape, while protecting property against flood damage. The use of different topographic levels creates an interesting and continuous ground floor, minimizing a potential divide between house and street, usually resultant from the placement of houses above street level.

Limitations
The house, however, does not contemplate a continued livelihood for its inhabitants in the event of a flood. Simply protecting property against damage, the designers also miss the opportunity to enhance a sense of neighborhood (the house is designed as a single, isolated element).

General features and lessons
The application of different materials in terms of durability creates an awareness of the surrounding natural space (the house is designed to cope with the temporary presence of water and this can be perceived throughout the year). Such strategy can certainly be applied and further developed in future designs for flood-prone zones.

3.2.5 Case Study 7: Hopper Howe Sadler’s House

General Information
Project name: Hopper Howe Sadler’s House
Location: Flood plain, UK
Date designed/planned: 2008
Size: Single-family house 150 m2, plot 270m2
Team: Hopper Howe Sadler (based in Newcastle)
Proposal Overview

“Hopper Howe Sadler’s House” is designed for areas adjacent to water bodies. The designers propose a floating volume that goes beyond the traditional static home, suggesting what they refer to as a "dynamic response to a dynamic problem” (Norwich Union and Royal Institute of British Architects 2008b, 13).

The team proposes a “contemporary family home” (Norwich Union and Royal Institute of British Architects 2008b, 13), clearly divided in two main zones: an indoor living space, conformed by prefabricated volumes, supported by a buoyant base containing the outdoor living area.

Design Analysis

*Section and Floor Plans to scale*

![Diagram](image)

Figure 3-26 Hopper Howe Sadler’s House, Section of the house during a low tide (top), followed by a Section of the house during a flood of 0.6 meters (bottom)
Source: Karen Paiva Henrique, adapted from “Water Level-fighting Houses” (2009, 97)
Figure 3- 27 Hopper Howe Sadler’s House, Second/Upper floor plan (left), and First/Lower floor plan (right)
Source: Karen Paiva Henrique, adapted from “Water Level-fighting Houses” (2009, 97)
Exploded 3D Diagram

HOPPER HOWE SADLER’S HOUSE
Floodplain, UK

SKIN
Steel and Glass pre-fabricated elements

STRUCTURE
Concrete Pontoon cast in situ

PROGRAM
Partially Sunken Ground Level, connected with an open Green Space

SITE
Sloped Riverine Terrain

Figure 3-28 Hopper Howe Sadler’s House, Exploded Perspective
Source: Karen Paiva Henrique
Site
The house rests on a platform shaped according to a difference of approximately 3 meters in the terrain’s topography, starting from the house’s entrance level and sloping down toward its contiguous water body. The design of the house is, as a result, conditioned to the sloped terrain. The house’s entrance is located on the highest portion of the slope while the other programmatic elements are placed according to the different levels of the site.

A small platform connects the house’s main entrance to the street and a long path connects the front of the house to a deck suspended above the water body, maximizing the contact of dwellers and visitors with the water. A parking space is located on the upper level of the terrain.

Structure
A concrete pontoon cast in situ, designed as the base for the house’s structure, floats in the event of a flood. The pontoon is attached to concrete columns through steel collars, which prevent the house from moving laterally. Above the pontoon, prefabricated steel elements structure the two volumes that conform the house’s private and social areas.

Skin
According to the team, the use of steel and the overall design of the social volume, reminiscent of a shipping container, take inspiration from the naval industry.

Large windows span across the house’s inner spaces, while the upper volume’s shape directs the user physically toward the view. On the ground floor, high windows bring light to the private areas partially sunken into the pontoon.

Infrastructure
No indication of alternative sources of infrastructure could be found during the design analysis. Therefore it is assumed that the house is dependent on traditional infrastructure provision.
Program
The ground floor is partially sunken below the entrance level and corresponds to the house’s private area (bedrooms). This private volume is adjacent to the outdoor space (backyard), which is surrounded by a wooden deck “floating” above water. The second floor, located at the main entrance level, encompasses the house’s social areas, with a large open-plan living room. The organization of the program guarantees maximum privacy for the inhabitant, with the bedrooms concealed from the street. The program is distributed in an arrangement very similar to a boat.

The outside green space, always kept above the water level, provides the user with a permanent outdoor area.

Significance and uniqueness of the project
The project offers a solution to recurrent floods through a structure that floats in accordance to fluctuations in the water level. The designers create spaces connected to nature through large windows and paths that direct the user to the adjacent water body. In fact, the house’s shape offers a constant reminder of the place where it is situated.

Limitations
One of the project’s limitations is the lack of a mobile platform to keep the house accessible when lifted by the high tide. The design also doesn’t offer any alternative infrastructure provision, relying solely on traditional methods for electricity, water and sewage treatment supply.

The proposal doesn’t describe sustainable features, but the decision of partially sinking the house in the concrete pontoon can certainly guarantee a better insulation for the sleeping container.

In the comments made by the Norwich Foundation Competition’s judging panel, the lack of a solution for debris moving under the house, which could potently become trapped and cause structural stress, was also pointed out as one of the proposal’s limitations (Norwich Union and Royal Institute of British Architects 2008b).
**General features and lessons**

The house designed by Hopper Howe Sadler adds another option to a relatively vast array of floating homes current on the market,\(^{24}\) this time focusing on a more specific type of terrain. Instead of assuming a flat platform, the architects utilize an irregular site as the starting point, inverting the traditional house arrangement (social ground floor and private upper floor). They invite the user to look at and walk toward the water, creating an environment extremely influenced by its presence.

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### 3.3 Rising Currents: Projects for New York’s Waterfront, NY\(^{25}\)

#### 3.3.1 Project Overview

In October 2012 the Hurricane Sandy arrived on the US East Coast. The extreme natural event, which meteorologists described as a ‘superstorm’ (Carlowicz 2012), led to rapidly accumulating waters, causing thousands to abandon their homes and leaving millions without electricity (Carcamo, Hennessy-Fiske, and Pearce 2012).

Nevertheless, the discussion on how to cope with recurrent and overpowering floods in New York started long before the Hurricane Sandy hit the area in and around New York City. “On the Water: Palisade Bay”, a record of research and design published in 2010, outlined the challenges posed by climate change, sea level rise, and future hurricanes in the region, which would lead to devastating flooding events, as the one witnessed in 2012.

The research was used as basis for the 2011 MOMA PS1’s architects-in-residency

\(^{24}\) Additional examples of floating homes currently available in the market are: the Float House by Morphosis, US (analyzed in this thesis in Chapter 4); the float homes in Maasbommel by Factor Architecten, NL; the floating neighborhood in IJburg by Marlies Rohmer, NL; among others.

\(^{25}\) The analysis presented in this chapter utilizes as references the book “Rising Currents: Projects for New York's Waterfront” (2011) and the website “http://narchitects.com/frameset_rising_currents.html”. Prior to the design analysis, a short introduction summarizes the proposal as described in the source material.
program entitled: “Rising Currents: Projects for New York’s Waterfront.” The program consisted of a workshop (2009-2010), an exhibition (2010), and a book (2011), and focused on the development of projects for specific locations in New York by five interdisciplinary teams. The groups embraced the idea of “a blurring of the edge between land and water” (Bergdoll 2011, 13), “going beyond existent real-state interests or current land-use regulations” (20), proposing absorptive landscapes, redesigning coastlines and landfills, and restoring wild-life. One team in particular focused on a new form of coastal development through the project “New Aqueous City”, developing the multi-family structure that will be analyzed here.

3.3.2 Case Study 8: New Aqueous City

General Information
Project name: New Aqueous City
Location: Bronx, Brooklyn, Jersey, Manhattan, Queens, Palisades, and Staten Island, New York, United States
Date designed: November 16, 2009–January 8, 2010
Consultants: Ed Purver, Anuradha Mathur and Dilip da Cunha, Arup NY
Team: Eric Bunge, Mimi Hoang (Team Leaders) Julia Chapman, Noah Levy, Seung Teak Lee, Meir Lobaton, Sanjukta Sen (Core Team Members). With nARCHITECTS office: Dominique Gonfard, Stephen Hagmann, Hubert Pelletier, and with: Andre Guimond, Juliana Muniz, Teo Quintana, Rebecca Garnett, Tyler Velten and Brett Appel

Context
The “New Aqueous City” proposal was developed as a master plan for the areas of Verrazano-Narrows Bridge (in Bay Ridge, Brooklyn, and forth Worth, Staten Island) and Sunset Park, Brooklyn. The team focused on developing a solution able to absorb both the impact of rising sea level and the future population growth of NYC, expected to increase by one million inhabitants in the next twenty years. Focusing on the need for a substantial number of new homes in the near future, the group embraced the possibility of developing the coast, usually restricted to leisure, with multi-family housing.
Proposal Overview

Master Plan
The “New Aqueous City” is composed by a number of complimentary parts: (1) habitable wave-attenuating piers offer areas for housing and leisure, combined to a set of treatment wetlands; (2) a series of man-made islands, connected by inflatable storm barriers, encourage silt accumulation and offer a natural environment resilient to storm surges; (3) a series of punctuated infiltration basins work as public parks when dry and allow water to permeate the urban environment in periods of heavy rain. The master plan also proposed new transportation systems, with the implementation of a new a tram, connecting the 7 boroughs, and a biogas ferry. Besides housing, the master plan suggested the use of mobile program barges, and indicated the construction of commercial buildings and cultural facilities on the landside of the wave-attenuation piers.

General Policy
The entire proposal is based on a “Zoning Resolution” defined for the areas of intervention. The resolution is “part of the strategy to incorporate environmental policy into the overall proposal” (Bergdoll 2011, 104), outlining the requirements for future urban development.

Multi-family Housing
The proposal defines that any building located less than 6 meters above mean sea level is at risk from flooding in a Category 3 Storm and must, therefore, comply with a number of rules delineated by the team. Such guidelines define a specific multi-family housing typology, the “Aqueous Neighborhood”, resilient to sea level rise and storm surges.
Design Analysis: Aqueous Neighborhood

Section and Floor Plans to scale

Figure 3-29 Aqueous Neighborhood, Section B of the complex in normal conditions (top), followed by a Section B of the complex during a high tide (bottom)

Source: Karen Paiva Henrique
Figure 3-30 Aqueous Neighborhood, Section A (top), and Floor Plan at the Entrance Level (bottom)
Source: Karen Paiva Henrique
AQUEOUS NEIGHBORHOOD
New York, US

PROGRAM
Shared Green Space

SKIN
Each Unit presents its own facade composition

STRUCTURE
"T" Shape Steel Bridge resting on Stilts

INFRASTRUCTURE
Floating Treatment Wetlands

Figure 3-31 Aqueous Neighborhood, Exploded Perspective
Source: Karen Paiva Henrique
**Site**

The site is located above water, adjacent to the mainland. The water level is expected to vary, while the “Aqueous Neighborhood” remains static. The multi-family housing structure is connected to a system of floating pathways and treatment wetlands, which float, moving in accordance to the movement of the tides. The floating paths create a protective system against storm surges.\(^{26}\)

**Structure**

The multifamily housing complex is suspended by a ‘double-T’ structure similar to the structure of a bridge, which incorporates the building’s public spaces. The structural system is composed by two main vertical supports, resting on stilts above the water level, and one horizontal truss. It is assumed that the system would be constructed with steel.

In the event of a storm surge, the public space at the top of the ‘bridge’ will be used to rescue the “Aqueous Neighborhood” dwellers. The roof is accessible via the vertical elements that support the main structure, which house elevators and stairs, among other infrastructural components.

The ‘bridge’ structure suspends each individual building, which are located above the flood line (the distance between building and water corresponds to the flood risk level of the area in which the building is situated and the dweller’s preference to be located closer to the water).

**Infrastructure**

At the neighborhood scale, the floating treatment wetlands process all the liquid waste of the housing complex (37 square meters for a household of four). The treatment wetlands will be constructed as barges connected to flexible piers, assuming different positions vertically in accordance to variations on the water level. Because of its function, the entire system must resist high tides.

At the individual household scale, micro anaerobic digesters located inside the

\(^{26}\) The piers are “comprised of boardwalk segments supported on modular concrete porous wave deflectors (storm surge side), and of floating segments tethered to piles (protected side).” (Rising Currents, p.104)
neighborhood’s vertical supports (together with the elevators and the stairs) treat the solid waste, generating gas to fuel the houses’ cooking appliances.

**Skin**
Lightweight materials compose the building’s facades, minimizing the loads on the structural system. Each housing block within the system presents a different facade, alluding to the image of the different buildings that compose a traditional street.

**Program**
The definition of a public space on the roof of the complex transfers activities that would usually take place on the ground floor to the upper level of the structure. Conceptually the upper floor becomes the “public street”, to which the different residential buildings are connected, creating a shared space for community interaction.

**Policy**
The neighborhood’s primary structure (the ‘bridge’) is provided by the city, in a similar way that bridges are provided by local governments as a city’s essential infrastructure.

**Significance and uniqueness of the project**
The project offers an alternative to develop housing in a zone that would be typically marked as unsafe. The houses can exist regardless of varying water levels, while the mobility of pathways and treatment wetlands (approached as raised gardens) provide the inhabitants with the constant awareness of place.

The proposal also outlines alternatives for more sustainable living, offering a large scale plan for sewage treatment, in which each household benefits directly from the system’s production of fuels.

**Limitations**
The project can certainly be further developed in terms of its sustainable features. The innovative structural proposal lacks a deeper analysis about other systems that could be incorporated in the project (for example, energy could be harvested from the water’s movement at the connections between man-made islands or at the wave deflector piers).
General features and lessons

The “New Aqueous City” offers a solution to occupy areas prone to flooding going beyond the creation of leisure zones. It gives an overview of how a large-scale housing development could take place together with sustainable features. The combination of static and non-static structures (such as the mobile program barges) can certainly bring in-land activities closer to the coast, extending New York’s vibrant urban environment into the city’s waters.
CHAPTER 4 BUILT WORK

4.1 Make it Right Foundation, New Orleans

4.1.1 Project Overview

Hurricane Katrina ravaged Greater New Orleans on August 29, 2005, after the region’s levee system failed, flooding nearly eighty percent of the city and affecting 243,180 people, who had to share their homes with more than 1.2 meters of floodwaters (Feireiss 2009). After two years since the devastating event and in face of the limited progress on rebuilding the houses, especially at the Lower Ninth Ward (one of the neighborhoods most dramatically affected by the hurricane), the “Make It Right” foundation was established.

The “Make It Right” initiative is based on the concept of redeveloping New Orleans’ Lower Ninth Ward through the construction of safe, sustainable and low-cost homes for the area’s former inhabitants. The core idea is to integrate high design in the development of the new homes in order to achieve quality of life for each family and restructure the local community as a whole. Besides focusing on the reconstruction of the New Orleans’ neighborhood, the foundation seek to actively influence our world’s built environment, addressing broader issues such as the influence of construction methods and materials on global warming, at the same time responding to the impact of climate change on the way we build our homes. According to the team:

“MIR [Make it Right] does not showcase a new sustainability concept for a corporate headquarters, but rather deals with the normally neglected, the usually restrictive issues of the world: low-income, affordable, and sustainable houses, the housing of the masses – the architecture of daily life.” (Feireiss 2009, 9)

With a “strong aesthetic idea”, influenced by New Orleans’ vernacular architecture, and a “clear sustainable goal” (Feireiss 2009, 10), the foundation invited twenty-one
architecture offices, both from the United States and from abroad, to submit projects for the new houses. The designs were donations for the families in the Lower Ninth Ward and followed a set of guidelines established by the foundation, which focused on storm-resistance and water-damage prevention, and on reducing the consumption of our natural resources. According to the project guidelines, all the houses should be elevated above the flood-line (between 1.5 and 2.5 meters), be structurally engineered to withstand the pressures exerted by hurricanes, have water and mold-proof finishes, and present a safe raised area for evacuation (Feireiss 2009, 122). Furthermore, the houses, developed with an initial budget of 200 dollars per square foot, should follow Cradle-to-Cradle thinking and achieve LEED Platinum standards. The process of developing the new houses, from design to construction, involved several steps with emphasis on community participation, all documented in the book “Architecture in times of need: Make It Right rebuilding the New Orleans’ Lower Ninth Ward,” published in 2009.

The houses completed by the time of this analysis are here divided in four main typologies according to similar design characteristics shared by more than one house, or a unique characteristic that brings one project apart from the others. The resultant four typologies are: the “Two-Bay Shotgun”, the “Four-Bay Shotgun”, the “Float House”, and the “Adaptable Multi-Family” dwelling. Each typology is presented and analyzed in accordance to the framework established at the beginning of this research.

4.1.2 Case Study 9: Two-Bay Shotgun or Shotgun Single

Typology Overview
The “Two-Bay Shotgun” or “Shotgun Single” typology take inspiration from traditional New Orleans’ style, broadly disseminated in the region from the late 1800s until the early 1900s. The houses are characterized by the linear distribution of spaces perpendicular to the street and a pitched roof sloping toward the houses’ longest dimension (Feireiss 2009). From the eleven model homes completed in the Lower Ninth Yard, seven follow

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27 The budget doesn’t include site preparation and atypical building systems, such as solar systems or gray-water recapture (Feireiss 2009, 123). All replicated models should later comply with a lower budget of 130 dollars per square foot.
the “Two-Bay Shotgun” style and were developed by the following architecture offices: Billes Architecture, BNIM, Constructs, Graft, Kieran Timberlake, Shigeru Ban Architects, and Trahan Architects. All the seven houses present similar design strategies, synthesized in the schematic floor plans, section and tri-dimensional diagram presented below. Unique features proposed in each house are introduced throughout the analysis of the design elements: Site, Structure, Skin, Program, Furniture, and Infrastructure and summarized in the Table 4-1.

Design analysis

*Section and Floor Plans to scale*

Figure 4-1 Two-Bay Shotgun, Section of the house in normal conditions (left) Section of the house during a flood (right)
Source: Karen Paiva Henrique
Figure 4-2 Two-Bay Shotgun, Ground floor plan (left), and Second floor plan (right)
Source: Karen Paiva Henrique
Exploded 3D Diagram

TWO–BAY SHOTGUN
New Orleans, US

INFRASTRUCTURE
Upper windows-cross ventilation
Ground Floor Cistern - Rain water collection system
Solar Panels

SKIN
Roof and facades merged into one element

SPECIAL ELEMENT
Safe area for rescue in the attic

PROGRAM
Porch space reminiscent of New Orleans' traditional houses

STRUCTURE
Second floor resting on stilts, elevated above the ground level

Figure 4-3 Two-Bay Shotgun, Exploded Perspective
Source: Karen Paiva Henrique
Site
The houses were built in the original Lower Ninth Ward’s plots, with dimensions ranging between 12 x 32 meters and 9.1 x 33.5 meters. Even if not ideal in size and proportions, the “Make It Right” foundation opted to maintain pre-Katrina property lines in order to sustain the image of the original neighborhood and offer continuity to its former inhabitants.

The houses were designed envisioning the protection of the structures, which must be vacated in the event of a flood. Therefore no alternative means for access are part of the proposals. The houses become completely isolated during a flood.

Structure
The houses are conceived as static structures raised above the flood elevation line, remaining in place during a flood while water flows freely under the building. All the houses grouped under this typology have their structures elevated 1.5 meters to 2.5 meters above grade level, in order to protect the property from damage during a flood. The resultant covered open space on the ground level is defined by a set of concrete pillars cast in situ. When left opened, such space is used both for water storage and parking.

Some proposals, however, opted to enclose this space. In order to minimize the separation between the housing object and their plots, usually resultant from raising the structures, some designers chose to continue the houses’ facade down to the point where the house’s structure meets the site (BNIM), while others raised the landscape until it touches the second floor level (Shigeru Ban Architects). Such strategies are able to visually connect the houses to the ground, from which they still remain physically separated, potentially preventing the accumulation of debris under the structure.

Skin
In all “Two-Bay Shotgun” houses, the skin is treated as a “high-performance surface,” with special attention given to the houses’ rooftops. In almost all designs under this category (Trahan Architects, Graft Design, Billes Architecture, and Kieran Timberlake), rather than merely following the vernacular shotgun style, the gable roof becomes the
architectural expression of the composition and merge with one or more facades, creating a continued element that shapes the building. In this element, sustainable features such as solar panels, water collection systems, and passive ventilation are explored.\textsuperscript{28}

\textit{Infrastructure}

Following the predefined competition guidelines, all the proposals aim at a certain level of self-sufficiency in terms of energy and water provision. All the houses harvest energy from the sun through solar panels, collect rainwater to be used in toilets and irrigation systems, and control heat gain/loss through optimized building envelopes, geothermal systems, and passive ventilation. Yet, all the houses analyzed under this category still rely on some form of traditional infrastructure provision, such as potable water supply, and sewage lines.

\textit{Program}

Six of the seven model homes here analyzed present a floor plan divided into living room (front) and bedrooms (rear), organized linearly, adjacent to a corridor and service area (kitchen and bathrooms) of smaller width.

With the exception of Trahan Architect’s proposal, all houses present a front porch located at the end of a set of stairs. This space represents the connection of the houses’ inhabitants with the neighborhood and it is reminiscent of New Orleans’s traditional homes. On the rear portion of the houses, a smaller porch connects dwellers visually and/or physically to the terrain.

All seven houses define the attic as a refuge space. In Shigeru Ban’s proposal, this space is further explored as a future expansion area for the house.

\textit{Furniture}

Shigeru Ban’s house is the only built house from the “Make it Right” Foundation which focuses on the furniture as an integral element of the design, functioning both as storage

\textsuperscript{28} Trahan Architects described the roof in their design as a “quasi metabolic screen”, conformed by a pre-fabricated structure of louvers encompassing passive and active sustainable systems. (Make It Right Foundation 2012)
space and as an active part of the house’s structure. The house’s exterior walls are comprised of pre-fabricated “Structural Furniture Units” (SFUs), consisting of “C-channel” wooden panels. These are able to withstand greater parallel lateral forces, such as the ones exerted by hurricane winds, providing structural bracing to support the roof, and allowing for an open plan arrangement. The furniture units are located on the house’s elevated floor, hence protected from any damage caused by its contact with the water. Besides its structural and programmatic qualities – designing the furniture as part of the walls maximizes not only the storage space, but also the free open space within the unit–, the SFUs help to maintain the inner temperature of the house, acting as a thermal barrier from outside temperature variations (Figure 4-4). The storage capacity provided by the furniture units allows for the protection of innumerable personal belongings, and could be further explored as storage space for potable water and batteries, for example, if the house remained occupied during a flood.

Figure 4-4 Shigeru Ban’s House, Axonometric View
Source: “Architecture in times of need” (2009, 235)
<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>SKIN</th>
<th>INFRASTRUCTURE</th>
<th>PROGRAM</th>
<th>FURNITURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BILLIS ARCHITECTURE</td>
<td>1.5 meters above ground</td>
<td>Solar Panel/Rainwater Collection</td>
<td>Attic: Storage/Emergency Refuge</td>
<td></td>
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<tr>
<td></td>
<td>High-Performance Surfaces</td>
<td>Permeable Surfaces: Less Water Runoff</td>
<td>Front/Back Porch: Neighborhood Connection</td>
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<td></td>
<td>Impact Resistant Windows</td>
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<td></td>
<td>High-Performance Surfaces Skin extends down to the ground level</td>
<td>Rain Harvesting System</td>
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<tr>
<td>CONSTRUCTS</td>
<td>1.8 meters above ground</td>
<td>Solar Pannels – Energy Collection</td>
<td>Ground Floor: Parking</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Attic: Emergency Refuge Front/Back Porch: Neighborhood Connection</td>
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<td></td>
<td>Impact Resistant Windows</td>
<td>Permeable Surfaces: Less Water Runoff</td>
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<tr>
<td>KIERAN TIMBERLAKE</td>
<td>1.8 meters above ground</td>
<td>Solar Panels/ Rainwater Collection</td>
<td>Ground Floor: Parking/Water Storage Attic: Emergency Refuge</td>
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</tr>
<tr>
<td>SHIGERU BAN ARCHITECTS</td>
<td>1.5 meters above ground</td>
<td>Permeable Surfaces: Less Water Runoff</td>
<td>Front Porch: Neighborhood Connection Attic: Emergency Refuge</td>
<td>Structural Furniture Unit (SFU) Hurricane Resistant</td>
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<tr>
<td></td>
<td>Skin extends down to the ground level</td>
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<tr>
<td>TRAHAN ARCHITECTS</td>
<td>1.5 meters above ground</td>
<td>Solar Heating/ Energy Collection Pannels Rainwater Collection</td>
<td>Ground Floor: Water Storage Attic: Emergency Refuge Front/Back Porch: Neighborhood Connection</td>
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<tr>
<td></td>
<td>High-Performance Surfaces</td>
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</tbody>
</table>

Table 4-1 Two-bay Shotgun Houses, Individual Design Features
Source: Karen Paiva Henrique
Policy
All houses analyzed in Chapter 4 follow national and local building codes and specific guidelines set for the project by the “Make It Right” team. Therefore all solutions implemented represent interpretations of current building codes.29

4.1.3 Case Study 10: Four-Bay Shotgun or Shotgun Double

Typology Overview
From all the single-family model units already completed in the New Orleans’ Lower Ninth Ward, three take inspiration from the “Four-Bay Shotgun” typology. This category includes designs that present a floor plan divided into two parallel sections of similar width, separated either by a wall or a hallway. Projects under this category include the “Lagniappe House,” by Concordia, the “New Orleans Prototype House,” by Eskew+Dumez+Ripple (EDR), and the model home designed by Adjaye Associates (for special features of each design see Table 4-2).

Design analysis
Section and Floor Plans to scale

![Section and Floor Plans to scale](image)

Figure 4-5 Four-Bay Shotgun, Section of the house in normal conditions (left) and Section of the house during a flood (right)
Source: Karen Paiva Henrique

29 The same is true for all typologies analyzed in Chapter 4.
Figure 4-6 Four-Bay Shotgun, Ground floor plan (left), and Second floor plan (right)
Source: Karen Paiva Henrique
FOUR-BAY SHOTGUN
New Orleans, US

INFRASCTURE
Rainwater / Solar Power harvesting systems
Ground Floor Cistern

SKIN
The design allows for the customization of the facade

PROGRAM
Stairs with areas for "stoop-sitting"

STRUCTURE
Second floor resting on stilts, elevated above the ground level

Figure 4-7 Four-Bay Shotgun, Exploded Perspective
Source: Karen Paiva Henrique
Site
Similar to the “Two-Bay Shotgun,” the “Four-Bay Shotgun” houses are located in a predefined site, following similar dimensions to the first. The houses are also elevated from the ground and water is allowed to flow freely through the site in the event of a flood, when the houses become isolated.

Structure
The houses under this category are raised 1.5 to 2.5 meters above grade level, resting on concrete pillars. While in the Adjaye Associates’ model home this space is enclosed, in the “Lagniappe House,” by Concor, the space under the house is designed as an open gathering place, and in the “New Orleans Prototype House,” by EDR, it is used for parking and rainwater collection storage.

Skin
The three proposals allow for the customization (full or partial) of the building’s elevations according to the user’s preferences. The house designed by Concordia presents hurricane shutters that can also be customized.

Infrastructure
Similar to the “Two-Bay Shotgun” typology, the houses adopt solar panels, rainwater harvesting systems, and passive ventilation. Also similar to the houses previously analyzed, the “Four-Bay Shotgun” houses rely on the traditional grid for partial infrastructure provision.

Program
The houses under this typology are divided in two parallel sections with similar width, generally defined as the living and the sleeping areas. The three model homes present front porches connected to generous areas for “stoop-sitting,”30 a feature present in New Orleans’ traditional houses, providing a space for encounters and hence facilitating contact between neighbors.

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30 “Stoop-sitting”: a set of stairs with two different step heights, one serving as access to the upper floor, while the other adopts the height of a conventional bench.
On the “Lagniappe House” this gathering space is extended under the dwelling. The designers define the covered area in the ground floor, adjacent to the street, as a space to be used for group activities. At the same time, a similar area in the rear of the house creates a more private setting for relaxation. Another semi-public space is provided on the house’s second floor to be used as safe haven during an extreme flooding event, serving as a space for interaction between neighbors in adjacent houses at any other time of the year.

Additional gathering spaces are also part of the Adjaye Associates’ design. In their approach, the backyard is reinterpreted by an open space located above the house, covered by a canopy collecting water and harvesting energy from the sun, at the same time emphasizing the presence and significance of such gathering space. This area could be utilized during a flood, providing the family with an open space safeguarded from floodwaters.

<table>
<thead>
<tr>
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<th>SKIN</th>
<th>INFRASTRUCTURE</th>
<th>PROGRAM</th>
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<tbody>
<tr>
<td>CONCORDIA</td>
<td>2.4 meters above ground</td>
<td>Solar Panels/ Rainwater Collection</td>
<td>Ground Floor: Parking/Leisure/Water Storage Elevated Deck: Emergency Refuge Front/Back Porch: Neighborhood Connection Front Stairs – Stoop Sitting</td>
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<td>Gray Water Recycling Systems</td>
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<tr>
<td>EDR</td>
<td>1.8 meters above ground</td>
<td>Customized Hurricane Shutters</td>
<td>Ground Floor: Parking/Leisure/Water Storage Front/Back Porch: Neighborhood Connection Attic: Storage/Emergency Refuge</td>
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<td></td>
<td>Solar Heating/ Energy Collection Pannels</td>
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<td>Rainwater Collection</td>
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<td>Permeable Surfaces: Less Water Runoff</td>
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<tr>
<td>ADJAYE ASSOCIATES</td>
<td>1.5 meters above ground</td>
<td>Impact Resistant Windows Skin extends down to the ground level</td>
<td>Terrace: Gathering Space/Emergency Refuge Front/Back Porch: Neighborhood Connection</td>
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<td>Solar Panels/ Rainwater Collection</td>
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</table>

Table 4-2 Four-bay Shotgun Houses, Individual Design Features
Source: Karen Paiva Henrique
4.1.4 Case Study 11: Float House

Typology Overview
The “Float House” was designed by Morphosis in collaboration with the UCLA Department of Architecture and Urban Design (AUD). The house follows the “Two-Bay Shotgun” style in terms of program distribution, but it is set apart from the other projects because it floats in the event of a flood.

Design analysis
*Section and Floor Plans to scale*

Figure 4-8 Float House, Section of the house in normal conditions (top)  
Section of the house during a flood (bottom)  
Source: Karen Paiva Henrique
Figure 4-9 Float House, Ground floor plan (right)
Source: Karen Paiva Henrique
**FLOAT HOUSE**
New Orleans, US

**PROGRAM**
"Two-Bay Shotgun" floor plan arrangement

**SKIN**
The *shell*: prefabricated skin with operable hurricane shutters

**INFRASTRUCTURE**
The *chassis*: prefabricated base to which all sustainable features (Rain water/ Solar power harvesting systems, geothermal system) are connected

**STRUCTURE**
Concrete foundation cast in situ, supports guiding poles that prevent the house from moving laterally

Figure 4-10 Float House, Exploded Perspective
Source: Karen Paiva Henrique
Site
Situated in a 9 x 33.5 meters site, the house sits on a platform located 1 meter above the street level. When a flood occurs, the house floats in place, allowing water to freely flow through the site. Similar to other strategies analyzed, the house becomes inaccessible during a flood.

Structure
Resting on a concrete base cast in situ, the entire structure rises when confronted by rising waters. In order to prevent the house from drifting laterally, the structure is connected to guiding poles that extend deeply into the ground.

Besides its base, the entire structure is pre-fabricated and composed by two parts: a chassis and a shell. The chassis consists of a “single unit of expanded polystyrene foam coated in glass fiber reinforced concrete” (“FLOAT House” 2012), with all systems and anchors preinstalled. The shell, made of insulated wall and roof panels, is attached to the chassis.

Skin
The “Float House” skin, made of prefabricated components, adopts efficient materials able to sustain the house’s inner temperature for longer periods of time. All windows present hurricane shutters, protecting the structure from storm surges and debris.

Program
As previously stated, the house follows the “Two-Bay Shotgun” style and is composed by rooms organized linearly, connected to a parallel corridor. Located only one meter above ground level, the house sustains a higher visual and physical connection between its interior and the neighborhood. According to the designers, the New Orleans’ porch culture is preserved and emphasized through the low elevation of the house’s first floor, made possible by its ability to rise in the event of a flood. The proximity of the house to the street allows a greater interaction between inhabitants and their neighbors, fostering the creation of community bonds.
Infrastructure

The structure’s pre-fabricated chassis is responsible for generating and sustaining its water and power needs. Solar energy is harvested from the sun, stored, and converted in the chassis. All energy produced exceeding the inhabitants’ needs is redirected to the city’s energy grid. Rainwater is collected on the sloped roof and filtered on the chassis for daily use. Efficient materials and appliances minimize energy loss and water consumption, while a geothermal system keeps comfortable temperatures within the house.

Although the “Float House” is self-sufficient, able to function even if the city’s infrastructural grid is disrupted by a major climate event such as a hurricane, the team emphasizes that the house wasn’t designed to remain occupied during such an event. The proposal, however, certainly serves as inspiration for the design of self-sufficient homes in areas affected by tidal flooding, but with no direct threat to life.

4.1.5 Case Study 12: Adaptable Multi-Family House

Typology Overview

After the first design phase architects were again invited to submit projects for the Lower Ninth Ward, now focusing on multi-family duplex homes. Four of these designs are already part of New Orleans built environment and represent houses not only structured for more than one family, but that offer a great possibility for adaptation in terms of their program. These houses were designed by: Atelier Hitoshi Abe, Bild Design, Gehry Partners, and Waggonner & Ball Architects (for special features of each design see Table 4-3).
Design analysis

Section and Floor Plans to scale\textsuperscript{31}

Figure 4-11 Adaptable Multi-Family House, Section of the house in normal conditions (left), Section of the house during a flood (right)

Source: Karen Paiva Henrique

\textsuperscript{31} Since the houses analyzed under this category present a vast array of floor plans and sections, with diverse arrangements that couldn’t be synthesized in one scheme as in the previous examples, the house designed by Atelier Hitoshi Abe was chosen to exemplify the typology.
Figure 4-12 Adaptable Multi-Family House, Ground floor plan (left), and Second floor plan (right)
Source: Karen Paiva Henrique, adapted from “Make It Right: Architects In Depth,” Hitoshi Abe Design Submission
ADAPTABLE MULTI-FAMILY HOUSE
New Orleans, US

MIRRORED SECTIONS
Atelier Hitoshi Abe

MISMATCHED SECTIONS
Bild Design, Waggonner & Ball Architects

SECTIONS WITH MULTIPLE FLOORS
Gelry Partners

INFRATESTRUCTURE
Rainwater/ Solar Power harvesting systems

PROGRAM
The houses are composed by two different sections and their arrangement defines specific characteristics for each design

STRUCTURE
Second floor resting on stilts, elevated above the ground level

Figure 4-13 Adaptable Multi-Family House: Exploded Perspective
Source: Karen Paiva Henrique
Site
Situated on a plot of similar size to the previously analyzed homes (12 x 32 meters), the multi-family houses are able to achieve a higher density, while sometimes resulting in a smaller footprint.

Structure
All four designs classified as “Adaptable Multi-Family Houses” are raised from the ground floor, located above a set of concrete pillars, and provide covered spaces for parking. Each structure is divided in two sections and the relationship between these defines specific characteristics in each composition (see diagrams in Figure 4-13).

While most of the houses are located above the highest flood elevation, one of the houses is designed with half of its structure placed closer to the flood line. In order to secure the connection between inhabitants and neighbors, at the same time maintaining a sense of security and permanence to the homeowner, the office Bild Design envisioned a ‘split-level’ house. Approximately half of the structure’s built area is located 2.8 meters above the ground level, secured from the contact with water, while the other portion is located closer to the level of the street. Even if the latest might require a higher maintenance due to its proximity to recurrent floodwaters, the office refrains from the widespread solution adopted in the Lower Ninth Ward of simply elevating the entire home at the same height. Such design could be further explored with the use of more resistant materials, increasing the durability of the house’s lower section and creating a constant sense of awareness towards the transient place where the house is located.

Skin
No special strategies are described by the designers in the development of the facades, besides the use of hurricane shutters in the house by Build Design and specific aesthetic features applied in each proposal.

Program
One of the most important characteristics of this typology is the potential for adapting its program. Each house is designed for two families, but offers the possibility to be converted into a single-family house, a renter/tenant building, or a live/work structure
(allowing families to pursue a higher economic stability). While most of the houses remain unaltered in face of the temporary presence of water, all of them offer innumeros opportunities for future living arrangements. This flexibility is achieved through the transitional zone created in between the two units, which is treated either as a simple removable wall (Bild Design, Gehry Partners, and Waggonner & Ball Architects.), or as a space to be shared between inhabitants of one or two families (Atelier Hitoshi Abe).

Regarding the structure’s number of floors, providing multi-story houses allowed the designers to create multiple outdoor spaces. Gehry Partners’ design adopts quality of outdoor space as the core of their strategy, proposing a taller housing structure with ample outdoor living areas spread throughout the design.

Infrastructure
Most of the houses present sustainable features similar to the houses previously analyzed (e.g. rain water collection, solar panels, and geothermal systems), but, also similar to the former designs, rely on traditional sources for partial infrastructure provision.

<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>SKIN</th>
<th>INFRASTRUCTURE</th>
<th>PROGRAM</th>
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<tbody>
<tr>
<td>ATELIER HITOSHI ABE</td>
<td>1.8 meters above ground</td>
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<td>Ground Floor: Parking</td>
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<td>Flexible Program:</td>
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<td>Residential/Rental/Work</td>
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<tr>
<td>BILD DESIGN</td>
<td>Split Level Structure</td>
<td>Hurricane Shutters</td>
<td>Ground Floor: Parking</td>
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<td></td>
<td>1.5 and 2.8 meters from the ground</td>
<td>Solar Panels/ Rainwater Collection</td>
<td>Parking/Leisure/Water Storage</td>
</tr>
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<td></td>
<td></td>
<td>Permeable Surfaces: Less Water Runoff</td>
<td>Flexible Program:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Residential/Rental/Work</td>
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<td></td>
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<td></td>
<td>Front Porch: Neighborhood Connection</td>
</tr>
<tr>
<td>GEHRY PARTNERS</td>
<td>Two-Story Structure</td>
<td>Solar Panels/ Rainwater Collection</td>
<td>Ground Floor: Parking</td>
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<tr>
<td></td>
<td>2.8 meters from the ground</td>
<td>Geothermal System</td>
<td>Multiple Elevated Gardens</td>
</tr>
<tr>
<td>WAGGONER &amp; BALL ARCHITECTS</td>
<td></td>
<td>Solar Panels/ Rainwater Collection</td>
<td>Front Porch: Neighborhood Connection</td>
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<td></td>
<td></td>
<td>Recaptured lavatory and shower water</td>
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</tr>
</tbody>
</table>

Table 4-3 Adaptable Multi-family Houses, Individual Design Features
Source: Karen Paiva Henrique
4.1.6 Significance and uniqueness of the project

Since all the houses developed by the “Make It Right” foundation share similar strategies and design features, it seems natural to analyze the qualities and limitations of the project as a whole. The houses built in the Lower Ninth Ward bring a unique component to the design of houses for flood-prone zones: the establishment of low-cost houses in an area profoundly affected by an extreme natural disaster. Besides the wide spread use of sustainable systems and the will to facilitate community building, also present in the projects analyzed in Chapter 3, the houses implemented in a post-Katrina New Orleans introduce the need for both replicable (and therefore cheaper) and customizable models, a contradictory binary that most designers chose to embrace.

All the houses were designed focusing on sustainable features, creating partially self-sufficient structures in terms of energy and water provision, and lessening the inhabitant’s dependency on natural resources. Furthermore, the adoption of such features allowed architects to reinterpret traditional design elements, creating interesting built forms able to emphasize its function through design, such as the unique sustainable roof created by Traham Architects.

Even if most of the houses analyzed were designed in isolation, the more recent multi-family typology focuses on a play of volumes between two interconnected houses resulting in interesting arrangements, such as the split-level home of Bild Design, which can certainly be further explored in the design of more flexible neighborhoods located in the floodplain.

4.1.7 Limitations

Almost all the projects rely on raising their structures from the ground, disconnecting the house from the urban environment. With the exception of the “Float House,” flood-response features that could have been explored in such large-scale development remained underdeveloped. Even if the former New Orleans’ inhabitants are accustomed to live a few steps above the ground, the reconstruction of an entire neighborhood
offered the chance to push the boundaries beyond traditional structures built on stilts, exploring alternatives to the model of raised homes.

While the designers widely applied alternative technologies for harvesting energy and water, while controlling the homes’ inner temperature, alternative technologies dealing with the relationship between structures and the temporary presence of water were mostly ignored. If the idea was to utilize sustainable sources for energy and water provision so these systems become more common, hence economically viable, the same approach was not adopted when confronting the special conditions and possibilities engendered by recurrent rising waters.

4.1.8 General features and lessons

The houses built by the “Make It Right” foundation encompass the effort of local and foreign architects to provide strategies for the reconstruction of an entire community. Each design brings innovative and unique features that can certainly be combined and further explored in houses designed for flood-prone zones. Above all, the foundation proved that it is possible to act on a community together with the local inhabitants, providing a voice for future dwellers in the design process and creating a model to be applied in places afflicted by similar distress.
CHAPTER 5 COMPARATIVE ANALYSIS

5.1 Achieving Flood Resilience Through Architecture

In “The Nature of Urban Design: A New York Perspective on Resilience” (2013), Alexandros Washburn defines adaptation as a combination of strategies able to reduce the vulnerability of our built and natural environments to current and future climate change scenarios. The author explains that, in order to adapt, one of the necessary steps is to achieve resilience through the constitution of systems able to “bend but not break” (Washburn 2013). Such systems, would have the ability to assume different forms when submitted to certain forces, returning to their previous conditions after these forces faded away. 32

From an architecture standpoint, flood resilience in human settlements depends on the capacity of buildings to structurally withstand the pressures exerted by flooding, changing their form, purpose, and/or position during the event, and moving back to their original condition after it is over. This capacity of changing form, purpose, and/or position is best described as flexibility, and its incorporation in one or more architectural elements becomes crucial in the establishment of flood resilient built forms.

The twelve case studies analyzed in Chapters 3 and 4 propose residential buildings designed to resist periodic inundations. All the houses accept the transient nature of their surroundings, incorporating flexible elements able to adapt to the recurrent and temporary presence of water. These solutions can be generally classified through their overall structure: built on stilts, above a buoyant platform, or with a permeable envelope.

32 The current literature on climate change adaptation also adds that, in face of natural hazards, resilience asks for multiple strategies including the system’s capacity to absorb and to learn from impacts – adapting, recovering, and reorganizing after the event is over (López-Marrero and Tschakert 2011).
33 The 2013 Oxford Online Dictionary defines flexibility as “the quality of bending easily without breaking” and “being easily modified.”
Nevertheless, the research shows that beyond technical solutions, structurally able to withstand flooding, all the houses are the result of an intricate composition of various architectural elements, both static and flexible, which relate to specific aspects leading to adaptation. These include the learning processes associated with flood resilience and the community’s capacity of mitigating the factors contributing to climate change and, consequently, to flooding.

In order to best evaluate the proposals individually and in comparison to others, each design was described according to the six architectural elements utilized for analysis (Site, Structure, Skin, Infrastructure, Program, and Furniture), and synthesized in Table 5-1. As previously mentioned, Site is defined as the project location and its specific lot (aspect described under the item Individual Plot). This concept was extended to the lot’s accessibility from the surrounding urban environment (aspect described in Access); Structure corresponds to the building’s supporting elements; Skin is determined by the layers that constitute the building’s facades; Infrastructure corresponds to elements that support the building (e.g. electricity, water, sewage systems); Program corresponds to the different functions within the building; and Furniture is defined by the objects that can be relocated within the space. Each component was then classified as flexible, if the element changed form, purpose, and/or position during a flood; or static, if the element remained unaltered regardless of flooding conditions, and were color-coded for their identification.

Following this analysis, this chapter will first outline initial and practical strategies for the design of structures able to cope with the temporary and recurrent presence of water, as proposed by the case studies analyzed, delineating the direct influence of the house’s structure in the application of other design elements. It will then present in further detail specific compositions for the inhabitation of the floodplain highlighting their unique contributions on achieving resilience through built form. Finally, it will summarize both sets of strategies, defining principals for the design of resilient architecture in environments prone to flooding.
<table>
<thead>
<tr>
<th>HOUSE 1</th>
<th>HOUSE 2</th>
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<tbody>
<tr>
<td>Amphibious Unit</td>
<td>Floating Flop</td>
<td>Floating House</td>
<td>Turnaround House</td>
<td>Gabion Walls</td>
<td>Topography</td>
<td>Topography</td>
<td>Permanently located above water</td>
<td>Hopper House</td>
<td>New Aqueous Neighborhood</td>
<td>Two-Bay Shotgun</td>
<td>Float House</td>
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<td>Not Pre-defined Houses float freely within the polder</td>
<td>Not Pre-defined Houses float freely in the polder</td>
<td>Not Defined Houses float freely in the polder</td>
<td>Prevent the entrance of debris in the site</td>
<td>Topography manipulated to protect house from floodwaters</td>
<td>Topography manipulated to protect house from floodwaters</td>
<td>Permanently located above water</td>
<td>Eileen Jamail's House</td>
<td>Sadler's House</td>
<td>Elevated from the ground through fill</td>
<td>Elevated from the ground built on stilts</td>
<td>Elevated from the ground built on stilts</td>
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<td>Floating Platforms, move according to the tides</td>
<td>Floating Platforms, move according to the tides</td>
<td>Floating Platforms, move according to the tides</td>
<td>Car/Truck dry polder, Boat/Amphibious Vehicle flooded polder</td>
<td>Car/Truck dry polder, Boat/Amphibious Vehicle flooded polder</td>
<td>Car/Truck dry polder, Boat/Amphibious Vehicle flooded polder</td>
<td>Floating Platforms, move according to the tides</td>
<td>Floating Platforms, move according to the tides</td>
<td>Elevating to the ground built on stilts</td>
<td>Floating on flooded conditions, it rests on the ground when water recedes</td>
<td>Floating on flooded conditions, it rests on the ground when water recedes</td>
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<td>Floating on flooded polder, it rests on the ground when the polder is dry</td>
<td>Floating on ground, changing position according to the tides</td>
<td>Floating on flooded polder, it rests on the ground when the polder is dry</td>
<td>Floating on flooded polder, it rests on the ground when the polder is dry</td>
<td>Wet-Proof structure</td>
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<td>Operable outer skin can be completely opened</td>
<td>Operable outer skin can be completely opened according to the tides</td>
<td>Foldout Shutters on the 2nd floor</td>
<td>Different Materials according to the tides</td>
<td>Different Materials according to its distance from the BFE</td>
<td>Different Materials according to its distance from the BFE</td>
<td>Operable Hurricane Shutters, closed during a hurricane</td>
<td>Operable Hurricane Shutters, closed during a hurricane</td>
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<td>Buffer Zone/Porch surrounds the structure</td>
<td>Buffer Zone/Porch surrounds the structure</td>
<td>Inter-changeable, ground floor activities move to 2nd floor during a flood</td>
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<tr>
<td>Self-Sufficient water, electricity, waste</td>
<td>Malleable expand according to the tides</td>
<td>Self-Sufficient water, electricity, waste</td>
<td>Protected from flood electrical located above BFE</td>
<td>Protected from flood electrical located above BFE</td>
<td>Protected from flood electrical located above BFE</td>
<td>Self-Sufficient waste treatment, natural gas</td>
<td>Self-Sufficient waste, electricity, heating</td>
<td>Self-Sufficient water, electricity, heating</td>
<td>Self-Sufficient water, electricity, heating</td>
<td>Self-Sufficient water, electricity, heating</td>
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<td>Multipurpose, storage, fold-out tables/beds</td>
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<td>Multipurpose, storage, fold-out tables/beds</td>
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Table 5-1 Flexible and Static Architectural Elements Adopted in Relation to Flooding

Source: Karen Paiva Henriques
5.1.1 Design Considerations in Architecture to Withstand Flooding

According to the examples analyzed, the first design decision in residential architecture for flood-prone zones is the adopted level of flexibility in its structure, which relate directly to the specific flooding conditions of each site. In houses located permanently above water, solutions vary from floating structures (“Implementation Rotterdam-IJsselmonde”), to houses built on stilts (“New Aqueous City”). In sites that present varying water levels, changing from a dry to wet condition, the strategies applied range among raised (“Pohkit Goh’s House,” “Two-Bay Shotgun,” “Four Bay Shotgun,” and “Adaptable Multi-Family”), buoyant (“Implementation Barendrecht,” “Implementation Gouda,” “Hope Howe Sadler’s House,” and “Float House”), and permeable built forms (“Turnaround House” and “Eleena Jamil’s House”). It can be inferred from the examples that buildings located in sites permanently inundated, or that present higher water levels for longer intervals, should adopt structures that prevent floodwaters from infiltrating the building envelope. Permeable structures become a viable option on sites where flooding occurs for shorter and less frequent periods of time.

Flexible structures, built above a floating platform that moves up and down in accordance to varying water levels, require the application of flexible infrastructure, with houses either connected to the grid through malleable ducts (“Floating Flop”) or disconnected from the grid through the implementation of sustainable features, such as solar panels and rainwater collection systems (“Amphibious Unit”, “Floating Flop”, and “Float House”). When buoyant structures are allowed to float freely within a pre-defined polder, special consideration must be given to the privacy of the users when neighboring houses drift closer together. A buffer zone can be created around the house with the implementation of a flexible skin operated in accordance to the level of privacy desired (“Amphibious Unit”).

Static structures, on the other hand, allow for the use of conventional and static infrastructure provision, which must be adapted to resist the prolonged contact with water. Electrical ducts must be located above the flood line, while mechanisms must be installed in hydraulic systems in order to prevent water backflow. Under this category, permeable structures (“Turnaround House” and “Eleena Jamil’s House”) require the
introduction of flexible program in the ground floor, with activities that can be easily relocated to the second floor during a flood. Kitchens, which are characterized by their heavy and expensive appliances, are safeguarded from floodwaters on mezzanines and second-floors. Living rooms can be converted into bedrooms, and are in some cases equipped with flexible furniture designed for emergency storage, with segments that fold out to become tables. These projects also require the implementation of water resistant materials to protect the building envelope from the temporary contact with floodwaters.

Raised, floating, and permeable structures allow for the application of both static and flexible means of access. While some proposals present secondary streets permanently located above the flood line (“Turnaround House” and “Eleena Jamil’s House”), others present floating platforms changing position according to the movement of the tides (“New Aqueous Neighborhood” and “Floating Flop”).

It is important to notice that, while the houses’ structure regulates the level of contact between inhabitants and floodwaters, the composition of other architectural elements, both static and flexible (Table 5-1), contribute to specific aspects that lead to resilience.

5.2 Architecture’s Influence on the Relationship Between Populations and their Surrounding Natural Environment

5.2.1 A Sense of Isolation [to human populations] and Connection [with nature]

The proposals “Implementation Barendrecht,” “Implementation Rotterdam-Ijsselmonde,” “Implementation Gouda,” “Hope Howe Sadler’s House,” and “Float House,” are based on flexible structures that rise together with the tides, keeping inhabitants and their homes safeguarded from variations in water levels. In order to float, the pre-fabricated houses rest on buoyant platforms. Three of the houses (“Implementation Rotterdam-Ijsselmonde’s Floating Flop,” “Hope Howe Sadler’s House,” and “Float House”) are tethered to the ground and prevented from drifting
laterally. The other two examples analyzed, “Implementation Barendrecht’s Amphibious Unit” and the “Implementation Gouda’s Floating Module,” suggest structures able to assume various positions within their flooded neighborhood.

The “Amphibious Unit” and the “Floating Module” challenge our definition of property, proposing a more fluid relationship between the housing structures and the dynamic ground upon which they rest. Such projects are based on flexible sites and create settings in which houses become one of the transient elements in the production of a constantly changing landscape. Designed to remain occupied regardless of flooding, and disconnected from any traditional form of access (such as roads or elevated pedestrian ways) these projects evoke a unique sense of isolation, conditioned by the lack of contact with other structures. During the low tide the structures rest on the ground. During the high tide the houses become islands. While inaccessible to the passersby, the temporary flooded environments expand the inhabitant’s personal space through reflection, depth, and a seemingly infinite surface, qualities intrinsic to their surrounding waters (Moore 1994, 200).

This sense of isolation from human populations and other built structures is contrasted with a higher connection between humans and nature, achieved through the house’s capacity to move from one position to another within the same polder, and through the introduction of facade systems that allow inhabitants to ‘open’ their homes to the surrounding environment (“Amphibious Unit” and “Floating Module”). Segments in which the floors open to the water below are also proposed in the “Floating Flop,” offering yet another form of connection between dweller and nature.

The physical contact between people living on the floodplain and their surrounding waters can certainly lead to a higher sense of stewardship toward the natural environment. One would care to preserve the quality of the water in direct contact with his/her residence. Following this idea, the “Floating Flop” and the “New Aqueous City” include in their proposals water treatment systems, directly improving the quality of the structure’s immediate surrounding waters.
5.2.2 Awareness of Flood Hazard

The floating dwellings incorporate water as a design element, creating structures that are responsive to it, but that still sustain a physical divide between the houses and their surrounding waters. The “Turnaround House,” “Eleena Jamil’s House,” and “Pohkit Goh’s House,” on the contrary, allow for rising waters to permeate the site and to coexist in direct contact with its inhabitants. In the “Turnaround House” and “Eleena Jamil’s House”, a static structure is combined to a flexible program. All the activities located on the houses’ first floor are relocated one floor above during the flood, allowing dynamic waters to occupy the ground level.

In order to cope with the pressures that water exerts on the house’s structures, inevitably wearing their materials out, all three projects follow a pre-determined flood elevation line (0.6 meters above ground level). The designed flood elevation is used as the line dividing lower thick impervious surfaces, constructed of long-lasting materials such as concrete and stone, supporting lighter and more fragile to water wall structures made of wood, metal, plaster, and glass. When applied across an entire neighborhood, the combination of various materials according to the flood elevation line goes beyond the practicality of maintenance, creating a strong awareness of flooding.

Current natural-hazard’s resilience advocates emphasize “the notion of ‘living with risk’” (López-Marrero and Tschakert 2011, 229). According to them, adaptation “is attained through social memory, the lessons that have been learned from past disasters, from accumulated experience and hazard knowledge” (230). These examples show strategies that inscribe the possibility of flooding in architecture through the use of specific materials and methods of construction. The “Turnaround House,” “Eleena Jamil’s House,” and “Pohkit Goh’s House” constantly remind their inhabitants of the possibility of flooding, providing multiple “water-level checks” in the form of walls and stairs that change material abruptly.

A less subtle awareness of flooding is proposed by structures built on stilts above the ground, such as the “Two-Bay Shotgun,” “Four-Bay Shotgun,” and “Adaptable Multi-Family House.” At the risk of creating what Anderson defines as a barren public realm,
characterized by “a network of passageways between parking spaces and gloomy undercrofts” (Anderson 2009, 6), the three housing typologies raise the house’s livable spaces to the second floor, leaving the ground level for parking and occasional leisure activities. Such spaces are kept free from any permanent objects regardless of weather conditions and are available to be occupied by floodwaters.

5.3 From Property Safety to Community Permanence

Flooding has social, economic, and emotional implications such as the costs related to relocation and repair, long term displacement, and “the ongoing fear and insecurity caused by the [flooding] experience” (Curtis 2009, 5). Hence, besides the protection of the housing structures, adaptation strategies must consider alternatives for the permanence of those inhabiting the floodplain before, during, and after the flood. Flood resilience can only be achieved through the minimal disruption in the lives of those affected.

All twelve proposals examined in Chapters 3 and 4 offer solutions able to protect the structures of the houses and the inhabitants’ personal belongings from the forces of rising waters, but only six of them allow for the permanence of affected populations during the flood. These proposals are: “Amphibious House,” “Floating Flop,” “Gouda Houses,” “Turnaround House,” “Eleena Jamil’s House,” and “New Aqueous City.” It is not expected that families will remain inside their homes in the event of extreme climate scenarios, such as a hurricane, but in face of non-life threatening flooding events, permanence can be achieved through design.

According to the multiple case-study analysis performed, allowing for families to remain inside their homes during a flood is intrinsically connected to the provision of nonstop access via elevated/floating pathways and alternative means for transportation, together with the uninterrupted provision of utilities, such as electricity and water. All the houses designed envisioning persistent habitation present these two features. The projects analyzed that allow for the permanence of their inhabitants during a flood event, offering both continuous access and infrastructure provision, are highlighted in Table 5-2.
<table>
<thead>
<tr>
<th>HOUSE 1</th>
<th>HOUSE 2</th>
<th>HOUSE 3</th>
<th>HOUSE 4</th>
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<th>HOUSE 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibious Unit</td>
<td>Floating Flop</td>
<td>Floating Module</td>
<td>Turnaround House</td>
<td>Gabion Walls</td>
<td>Eileen Jamil’s House</td>
<td>Permanently located above water</td>
<td>New Aqueous Neighborhood</td>
<td>Two-Bay Shotgun</td>
<td>Four-Bay Shotgun</td>
<td>Float House</td>
<td>Adaptable Multi-Family</td>
</tr>
</tbody>
</table>

**Site**
- Not Pre-defined
- Houses float freely within the polder

**Access**
- Floating Platforms, move according to the tides
- Car/Truck dry polder; Boat/Amphibious Vehicle flooded polder
- Regular (Lower) St/Upper Street connected during a flood
- Wet-Proof structure
- Elevated from the ground built on stilts

**STRUCTURE**
- Floating on flooded polder, it rests on the ground when the polder is dry
- Floating permanently, changing position according to the tides
- Floating on flooded polder, it rests on the ground when the polder is dry
- Wet-Proof structure
- Elevated from the ground through fill

**SKIN**
- Operable outer skin can be completely opened
- Operable outer skin can be completely opened according to season
- Foldout Shutters on the 2nd floor Different Materials according BFE
- Different Materials according to its distance from the BFE
- Operable Hurricane Shutters, closed during a hurricane
- Operable Hurricane Shutters, closed during a hurricane

**PROGRAM**
- Buffer Zone/Porch surrounds the structure
- Inter-changeable, ground floor activities move to 2nd floor during a flood
- Inter-changeable, ground floor activities move to 2nd floor during a flood
- Shared, open green space at the rooftop
- Ground Floor parking, access, and storage: Safe Haven
- Ground Floor parking, access, and storage: Safe Haven
- Ground Floor parking, access, and storage: Safe Haven

**INFRA-STRUCTURE**
- Self-Sufficient water, electricity, waste
- Malleable expand according with the tides
- Self-Sufficient electricity
- Protected from flood electrical located above BFE
- Malleable expand according with the tides

**FURNITURE**
- Multipurpose, storage, fold-out tables/beds
- Self-Sufficient waste treatment, natural gas
- Self-Sufficient water, electricity, heating
- Self-Sufficient water, electricity, heating
- Self-Sufficient water, electricity, heating
- Self-Sufficient water, electricity, heating

Table 5-2: Proposals That Allow the Permanence of Inhabitants During a Flood.
Source: Karen Paiva Henrique
5.3.1 Neighborhood Connectivity

While some of the proposals describe a user willing to adopt an alternative life-style during a flood, the projects able to delineate more feasible strategies to be applied in any urban development, incorporate alternative means for connecting the house to its surrounding neighborhood and to the city. The “Turnaround House” proposes raised pathways in front of each house, which are connected during a flood. The “Eleena Jamil’s House” configures a similar, however permanent, elevated pathway, combining the houses’ backyards into a raised pedestrian street. The “Floating Flop” and the “New Aqueous Neighborhood” utilize floating platforms connecting the housing structures to the main land. These flexible passageways guarantee the accessibility of inhabitants to other parts of the urban environment, as well as the contact between neighbors.

Flood risk is rarely experienced individually, since flooding usually affects entire communities instead of single homes, “so community solutions usually offer best protection” (Anderson, Homes for a Changing Climate, 2009, p.59). The “Turnaround House,” “Eleena Jamil’s House,” “Floating Flop,” and “New Aqueous Neighborhood” present solutions connecting multiple households, providing a framework for community flood resilience. As unexpected flood events can drive populations apart, planning for rising waters can bring populations together, as suggested by these examples.

Besides connecting multiple houses, the “Turnaround House” and “Eleena Jamil’s House” also propose several green-spaces spread across the neighborhood, which are designed to capture low floodwaters, slowly releasing them back into storm water collection systems. Such green areas have the potential to function as “soft green centers to the streetscape” (Anderson, Homes for a Changing Climate, 2009, p.62), enhancing public space. The “New Aqueous Neighborhood,” the “Amphibious Unit,” and some “Adaptable Multi-Family” houses also propose green areas in the form of elevated gardens, proving that architecture for flood resilience can have multiple effects.

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34 The “Gouda Houses” proposal, for example, assume inhabitants willing to find ‘creative’ means to access their houses, situated in marshy grounds, such as boats (flood season) and tractors (dry season).
improving “the quality of the environment to wildlife and humans alike” (Anderson, Homes for a Changing Climate, 2009, p.59).

5.3.2 Uninterrupted Provision of Utilities

The continuous provision of utilities is guaranteed by the careful design of systems able to endure or to adapt to flooding. In the “Turnaround House” all electrical components are located above the flood elevation line. The “Floating Flop” presents malleable ducts able to extend and contract in accordance to the level of the tides. The “Float House” suggests a structure connected to electricity and water supply systems, disconnecting from these in face of a flood.\(^{35}\) The “Amphibious Unit” and the “Gouda Houses” propose entirely self-sufficient structures in terms of water and electricity provision.

Six of the twelve residential projects examined propose partially to fully self-sufficient structures (“Amphibious House,” “Gouda Houses,” “Two-Bay Shotgun,” “Four-Bay Shotgun,” “Float House”, and “Adaptable Multi-Family”).\(^{36}\) These proposals align with the principle that large centralized systems, traditionally responsible for the provision of infrastructure, are more likely to fail in face of flood events then smaller decentralized ones (Ryan 2010). The houses adopt sustainable systems including, but not limited to, collecting water from the rain, harvesting energy from the sun, and utilizing composting stations for the treatment of residues. The idea of a self-sufficient architecture is closely related to the notion of “working together with nature, instead of against it” (Marshall 2013, 81).

The adoption of sustainable features enhances the connection between inhabitants and nature, especially when these are emphasized through design. In the “Amphibious Unit,” the solar-water collection system is a singular element in the design of the housing unit. In the “Two-Bay Shotgun” house designed by Traham Architects the roof acquires a singular shape, harvesting energy from the sun and collection water from the rain, at the same time protecting the structure from solar gain. In the “New Aqueous City,” the

\(^{35}\) During the event, the house sustains its inhabitants’ electrical and water needs.

\(^{36}\) For a summary of strategies adopted see Table 5-1.
filtering gardens represent a vital element in the landscape.

Resilience depends both on the capacity to adapt existing structures to current and future climate scenarios, and on the ability to mitigate the factors influencing the probability of further changes in our climate (Washburn 2013). Similar to adaptation, mitigation strategies can certainly be implemented in residential design. The adoption of sustainable strategies toward self-sufficiency works in favor of nature as a whole, and tackle the issues that actively influence climate change and rising seas. Rainwater collection and filtering systems installed in individual residences, together with other self-sustainable systems such as solar panels, minimizes the use of energy derived from fossil fuels for water treatment and distribution, and energy provision. Self-sustaining systems applied in individual houses, therefore, act directly on the use of fossil fuels, which release greenhouse gases in our atmosphere, and are directly responsible for increasing the earth’s temperature, accelerating the meltdown of icecaps and increasing the frequency and intensity of storms, all leading to flooding.

5.4 Five Principles for Achieving Flood Resilience Through Architecture

The comparative analysis of the twelve case studies presented in this thesis delineates a set of principals for architecture in floodplains, summarized as follows:

1. **Flood Resilient Architecture must be part of a Multi-Scale Approach**
   As previously stated, flood events usually affect entire communities, rather than a single household, often extending beyond the initially affected area to other parts of the city. Strategies utilized to prevent flood damage in one site can have a beneficial or detrimental effect in adjacent zones. As seen in the case studies in the Netherlands, well-integrated planning approaches accept flooding in one place in order to contain floodwaters from invading others. Certain solutions applied at the building scale, such as creating fill or dry-proof structures, are prohibited, preventing the dislocation of floodwaters to other parts of the urban environment. Hard-infrastructure projects are also carefully incorporated in order to avoid similar issues. These are a few examples of well-integrated multi-scale approaches that must be applied in zones prone-to flooding,
not only to protect one site, but also to keep entire urban settings safeguarded against the forces of rising waters. The definition of such approaches has a direct influence on the flooding conditions on individual sites, such as duration of flood and expected water levels, which directly influence architecture.

2. **Buildings must be detailed to physically withstand flooding.**

Following the specific conditions of flooding presented by each site, structures must be designed to physically withstand the forces of the water. To that extent, the houses are either kept apart from the water level (in sites with prolonged exposure to water), or incorporate specific methods of construction to protect the building envelope from damage due to its contact to accumulating waters (in sites where contact with floodwaters is inevitable, but temporary). Following the selection of an appropriate structure, additional strategies can be applied in order to create buildings capable to physically withstand flooding.

3. **Buildings must be designed with continuous access throughout the flood event.**

As important as the capacity of a housing structure to physically withstand flooding is to maintain its resident’s ability to move to and from the houses. The accessibility of houses located in flood-prone zones, before, during, and after a flood, guarantees the contact between neighboring houses and their access to other parts of the city, food supply and emergency provisions, and, occasionally, rescue.

4. **Infrastructure must be adapted to operate during a flood.**

In order to allow for the permanence of families inside their homes during the flood event, minimizing the disruption of the lives for those affected, the infrastructure responsible for water, electricity, heating, sewage collection, and communications (telephone and internet) must be adapted to remain functioning during the inundation. Infrastructural lines should be protected from the contact with water (electrical components must be located above the BFE and mechanisms must be installed in hydraulic systems in order to prevent water backflow) or alternative systems should be incorporated in order to provide utilities outside traditional infrastructural grids.
5. Design for flooding must consider the implications of architecture in the urban environment and in the way populations inhabit space.

Designing for flooding requires a holistic understanding of local flood risk and the possibilities that the temporary and recurrent presence of water engenders. The houses analyzed present specific design strategies that work in combination, not only to assist the inhabitants during a flood, but also to promote healthier indoor spaces and urban environments throughout the year. These focus, for example, on fostering community bonds and a sense of stewardship between populations and their surrounding natural environments, and can be combined in diverse ways in accordance to the needs of individual communities.

The strategies applied in combination by the twelve case studies analyzed were synthesized in Table 5-3. The table represents initial approaches to be adopted by designers according to the flood conditions of each site (expected duration and frequency of flood events) and the selected structure for the houses. It is important to notice that this table only presents the combination of strategies utilized in the examples analyzed by this thesis and can certainly be further explored and complemented by new combinations.
Table 5-3 Design Strategies for Flood-Prone Zones According to Specific Site’s Flooding Condition and Selected Structure. Source: Karen Paiva Henriques
Although alternative design strategies for the inhabitation of floodplains already exist, building a varied architectural lexicon for communities pursuing flood resilience, their implementation is still generally restricted by current local building codes. All the strategies examined in Chapters 3 and 4 reflect upon the regulations defining urban development in zones prone to flooding, either by complying with or defying them.

In order to analyze the differences between strategies that comply with local regulations and, for this reason, can be implemented, this chapter examines two different regulatory approaches: the National Flood Insurance Program (NFIP), in the United States, and “Improving the Flood Performance of New Buildings: Flood Resilient Construction,” in United Kingdom. These two approaches define distinct requirements for residential design in areas affected by flood events, leading to specific typologies, as shown by the houses built by the Make It Right Foundation, in New Orleans, and those proposed in the “Norwich Union competition: Flood-proof houses for the future” in London.

6.1 The National Flood Insurance Program (NFIP), United States

In the United States, areas at risk from recurrent flooding are denominated as Special Flood Hazard Areas (SFHAs). The National Flood Insurance Program (NFIP), a voluntary insurance plan administered by the Federal Emergency Management Agency (FEMA), regulates development in these areas, defining minimum requirements for: the elevation of the structures’ lowest floors, the installation of utility systems, the application of flood-resistant materials, and the use of the space located below the

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37 The NFIP aims at minimizing the loss of life and property damage resultant from inundations. Following the NFIP, any “substantialy damaged [with restoration costs exceeding 50 percent of the orginal value of the structure] and substantially improved building,” (Watson and Adams 2011, 137) must meet the standarts for flood-resistant construction for new structures. Incentives for meeting the requirements include credits given to communities and property owners who meet or exceed floodplain regulations, reducing their insurance rates.
The standards set by the NFIP must be followed by municipalities, which can also adopt more restricted regulations for the development of flood-prone zones. The International Building Code (IBC), together with the International Residential Code (IRC), and the American Society of Civil Engineers 24 (ASCE 24) complement the NFIP.

The data utilized by the NFIP is provided by FEMA in the form of Flood Insurance Rate Maps (FIRMs) that classify SFHAs as: V and VE Zones, coastal areas subject to velocity hazard through wave action; Coastal A Zone, with moderate wave action; and A Zone, defined as the base floodplain (Figure 6-1). Flood insurance maps determine the Base Flood Elevation (BFE) that must be followed by new constructions. BFEs account for wave effect and are determined as follows: V Zone, higher or equal to 3 feet (0.9 meters); Coastal A Zone, between 3 and 1.5 feet (0.9 and 0.45 meters); and A Zone, below 1.5 feet (0.45 meters). Flood insurance maps also define floodways\(^{38}\) that cannot be occupied by structures or fill in order to prevent possible dislocations of flood hazard to other areas.\(^{39}\) Local flood regulations usually require buildings to be located 1 foot (0.3 meters) or more above the BFE. This requirement is denominated Design Flood Elevation (DFE) and becomes the local reference to be adopted in any design located in the floodplain.

According to the NFIP, buildings situated in flood-prone zones “must be designed, constructed, and anchored to prevent floatation, collapse, and lateral movement resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy” (Watson and Adams 2011, 191). The NFIP requires that the structure’s lowest floors, configured by habitable spaces (besides parking, storage, and access), must be elevated above the BFE in order to assure that floodwaters won’t enter the building during the flood event.

\(^{38}\) “The floodway is the central portion of a riverine floodplain that carries floodwater flow downstream” (Watson and Adams 2011, 141).

\(^{39}\) The IRC defines that “in riverine flood hazard areas where design flood elevations are specified but floodways have not been designated, the applicant shall demonstrate that the effect of the proposed buildings and structures on design flood elevations, including fill, when combined with all other existing and anticipated flood hazard area encroachments, will not increase the design flood elevation more than 1 foot (305 mm) at any point within the jurisdiction.”
Buildings designed for V zones should have their lowest horizontal structural member elevated on open foundations (e.g. built above stilts). It is recommended that buildings proposed for Coastal A zones follow the same requirement. Compacted fill and walls, or crawl spaces, are allowed in A zones, while basements built below grade on all sides are not permitted in any flood-prone zone (Figure 6-2).
Figure 6-2 Design Requirements for Zone V (above) and Zone A (below – A: Minimum Requirement; B: Best Practice Suggestion)
Source: “Design for Flooding” (2011, 146-147)
In structural terms, building foundations must be designed and constructed to remain intact and functional during and after the flood. In V zones, buildings must be located above piers or pilings, while any walls built below the BFE must be designed to break away during a flood. In A zones, foundation walls and crawl spaces must present openings for the passage of water. In both V and A zones, all building components located at or below the BFE must be flood-resistant.\textsuperscript{40} Main structural elements should be designed with the possibility of being replaced through time.

The building envelope (floor, walls, openings, and roof) must prevent the penetration of wind, rain, and debris. Wet flood proofing, which allows water to enter the structure, is permitted only through variance and special exception, used for historical buildings, parking, and limited storage. Roofs must be designed to withstand uplift loads.

For any flood-prone zone, the NFIP defines that the space below the BFE must be used only for parking, access, and storage. Utility connections (electricity, water, sewer, natural gas) must remain intact during the flood or be easily restorable to service after the flood event. Mechanical, plumbing, and electrical (MEP) equipment must be placed above the Design Flood Elevation (DFE). Also, when possible, equipment should be located opposite from the expected floodwater flow. Backflow prevention must be installed on wastewater connections in order to prevent contamination of the building water supply and/or its interior.

Under the guidance of the NFIP, development in floodplains focuses on human and property safety. The idea of persistent habitation in the presence of a flood, explored by several proposals analyzed in this thesis and essential component on achieving resilience, is not addressed in the code. The house is conceived as a single, disconnected unit that must physically withstand the forces of water. Following the NFIP requirements, the “Two-Bay Shotgun,” “Four-Bay Shotgun,” and “Adaptable Multi-Family House,” analyzed in Chapter 4 (Figure 6-3), result in a group of structures elevated from the ground floor, which become completely isolated during a flood. These

\textsuperscript{40} According to the IBC, flood damage resistant materials are “capable of withstanding direct and prolonged contact – at least 72 hours -, with floodwaters without sustaining any significant damage that requires more than cosmetic repair” (Watson and Adams 2011, 182).
projects show that United States’ policy doesn’t contemplate the possibility of incorporating floodwaters in the inhabitants’ daily lives, while simply asking them to vacate their homes in the event of a flood. Additional strategies for the inhabitation of the floodplain, such as allowing for floodwaters to infiltrate the built structure (“Turnaround House” and “Eleena Jamil Architects’s House”), are prohibited, while the structures’ ground floor are restricted to parking, access, and storage.

Besides programmatic restrictions, the NFIP also presents other limitations. In “Design for Flooding” (2011), Watson and Adams point to FEMA’s shortsighted vision of future climate conditions. According to the authors, “NFIP minimum requirements do not account for future changes in floodplains due to land development, coastal erosion, or sea level rise” (136). Even when NFIP’s guidelines are met, the authors claim, these can be surpassed by events larger than current predictions. Furthermore, FEMA data does not account for shallow flooding caused by the overload of drainage systems in largely urbanized zones, where “debris accumulation, ice jams, and extreme events can contribute to flooding beyond the mapped floodplain boundaries” (137).

Figure 6-3 Projects developed for the Make it Right Foundation, New Orleans: “Two-Bay Shotgun” (Left), “Four-Bay Shotgun” (Center), and “Adaptable Multi-Family House” (Right)
Source: Karen Paiva Henrique
In spite of the clear limitations in current policy defining development in areas prone to flooding in the United States, recent architectural projects seem to be encouraging legislators to consider alternative design strategies in the reconstruction of environments severely damaged by flood events. The “Float House” by Morphosis, presents the first step toward the implementation of alternatives for flood-resistant architecture. The amphibious structure, built on a buoyant platform, was the first of its kind to receive an occupancy permit in the country (CBSNews 2014). This permission was only possible because the house meets all NFIP guidelines in static conditions. The buoyant component is adopted as an additional measure to withstand flood events larger than the 3 feet (approximately 1 meter) anticipated by the code for the site in which the house is located. Even if the permission issued for the construction of the “Float House” does not allow for the implementation of other amphibious projects previously analyzed in this thesis, such as the “Amphibious Unit” or the “Floating Module,” the house opened the precedent for future buoyant structures designed for floodplains in the United States.

6.2 “Improving the Flood Performance of New Buildings: Flood Resilient Construction,” United Kingdom

While building codes in the United States target property safety through the elevation of building structures, special guidelines have been delineated in the United Kingdom focusing on alternative strategies for the development of low-risk and residual flood-prone zones. The 2007 guidance, “Improving the Flood Performance of New Buildings: Flood Resilient Construction,” complements the Planning Policy Statement 25 (PPS25), which regulates the development of floodplains in England, and the government’s flood risk management strategy “Making Space for Water,” described in Chapter 2. The document also aims at adding to local planning and building codes in Wales, Scotland, and Northern Ireland. “Improving the Flood Performance of New Buildings” underlines three important concepts that summarize design approaches on environments affected by periodical inundations, entitled avoidance, resistance and resilience. As defined by the guidance:

41 The house is “properly elevated and meet specific foundation and anchoring requirements” (Fenuta 2010, 138) following the DFE defined by the NFIP, before it floats.
“**Flood avoidance** (at site level)
Constructing a building and its surrounds in such a way to avoid it being flooded (e.g. by raising it above flood level, re-siting outside flood risk area etc.)

**Flood resistance**
Constructing a building in such a way to prevent floodwater entering the building and damaging its fabric.

**Flood resilience**
Constructing a building in such a way that although floodwater may enter the building its impact is minimized (i.e. no permanent damage is caused, structural integrity is maintained and drying and cleaning are facilitated).” (Department for Communities and Local Government: London 2007, 9)

These concepts are crucial for the development of structures able to “cope with floodwaters and minimize the time for re-occupation after a flooding event” (Department for Communities and Local Government: London 2007, 8). According to the Department responsible for the guidance, re-occupation is considered as “a principal consequence of flooding which can have a profound impact on the health and livelihoods of those affected” (8).

Following basic flood parameters, such as depth, frequency, and duration of a flood (normally part of flood risk assessment studies), designers can select the most appropriate strategy for structures situated in low-risk floodplains. In places where the Design Water Depth (DWD) is below 0.6 meters, designers are advised to use “water exclusion strategies” (Department for Communities and Local Government: London 2007, 65), “keeping water out” of the structures through resistant materials and constructions with low permeability. Strategies following this approach include raising land to create high ground or elevating the structure’s ground floor to protect it from floodwaters. Access routes must be maintained in order to avoid the island effect on structures that become surrounded by water. The implementation of additional drainage systems must also be considered in new developments, in order to avoid the transference of flood risk elsewhere.

In locations where the DWD reaches or exceeds 0.6 meters, it is advised that designers utilize “water entry strategies” (Department for Communities and Local Government:
London 2007, 65), allowing water to infiltrate the building. This strategy is adopted in order to protect standard masonry structures, unable to withstand the pressures exerted by exterior water levels above 0.6 meters. These structures must guarantee fast drainage and cleaning after the flood. Design strategies under this guidance include the adoption of building materials resistant to water, with the ability to dry and retain their pre-flood dimensions during and after the flood.

The most interesting aspect of this guidance is the acceptance of floodwaters as part of the built environment in floodplains, delineating a set of strategies to cope with its presence. The water is not simply excluded from the structures. The decision to keep water out or allow it inside the buildings is made on an individual basis, leaving room for the implementation of alternative approaches. The guidance focuses on property safety, however it also takes into account the lives of those affected, guaranteeing their continued access during the flood through elevated emergency routes and their fast return after the event is over.

The inclusive nature of the guideline allows for the development of a larger set of architectural strategies in flood-prone environments, in comparison to United States’ building legislation, as proven by the examples part of the “Norwich Union Competition: Flood-Proof Houses for the Future,” analyzed in Chapter 3 (Figure 6-4). The “Turnaround House,” “Eleena Jamil Architects’s House,” “Pohkit Goh’s House,” and “Hopper Howe Sadler’s House” follow current UK building codes and offer a varied array of architectural solutions able not only to withstand the pressures of water, but also to allow the permanence of affected populations in some cases, while expediting their return after floodwaters recede in others.

The two regulatory approaches, NFIP and “Improving the Flood Performance of New Buildings,” present distinct ways of shaping development in areas prone to flooding. The first, more restrictive, conditions almost all residential buildings to be raised above the flood line, as shown by the houses built in New Orleans after the Hurricane Katrina (Figure 6-3). The second, more inclusive, allows for the proposal of a more vast array of innovative solutions able to relate to specific flood conditions of each site, as presented by the winning projects in the “Norwich Union Competition,” in London (Figure 6-4).
When residential development is permitted in flood-prone zones, building codes must be flexible enough to allow for responsible development, which includes the adoption of strategies consistent with the characteristics of each site. Furthermore, regulatory approaches must focus not only on the safety of populations and built structures, but also on minimizing the disruption of their daily lives. To this end, the British approach serves as example for authorities that wish to permit and regulate development in zones affected by rising waters.


CHAPTER 7 CONCLUSIONS

“It is time for a new approach that is sustainable from an environmental, technical, and economic standpoint, and that also has the potential to improve the quality of urban life” (Nordenson, Seavitt, and Yarinsky 2010, 45)

The forces of water are reshaping our world. Flood events, a natural phenomenon that is part of the history of cities adjacent to large water bodies, are increasingly becoming an inevitable reality affecting communities around the globe. As temperatures increase, rainy seasons become longer and more intense, and sea level rises, in combination with large widespread urbanization built upon often miscalculated, misplaced, and poorly maintained protective infrastructures, the condition of recurrent inundations will only become more acute. It is not realistic to consider that populations will simply abandon places they have inhabited for generations, even if threatened by natural hazards. It is also not likely that development will cease to occur in such borderlands. Hence it becomes imperative that we focus on strategies for adapting both new and consolidated urban forms in a time when climate extremes reshape floodplains, pushing its boundaries further inland.

Contemporary architectural solutions for the inhabitation of floodplains seem to stand against the solely implementation of hard-infrastructure projects, which often preclude a healthy relationship between populations and their contiguous water bodies. Such projects add to a discourse that challenge the efficacy of protective infrastructures designed to keep the sea out, contributing to the pursuit of environments in which water and land become more and more intertwined.

The projects analyzed in this thesis located in the Netherlands, the United States, and the United Kingdom attest not only to the ubiquity of flooding, but also to the diverse possibilities to address the issue. In an attempt to achieve flood resilience through architecture, all projects adopt flexibility in one or more architectural elements, generating structures able to adapt to the temporary and recurrent presence of water.
The comparative analysis of the twelve case studies presented in Chapters 3 and 4 unveil a set of principles to be followed in the design of flood resilient architecture. The first step is to identify the role that individual sites located in the floodplain have on the city’s overall flood-prevention and adaptation planning strategies. This will define specific flood conditions that must be understood in the adoption of the most appropriate structure, which must be able to physically withstand the pressures of water and to minimize the damage caused by the contact between the building envelope and rising tides. Sites in which the presence of water is permanent or prolonged require structures that minimize the contact between floodwaters and inhabitants, through structures that are raised or buoyant. Permeable solutions become an option for sites with less frequent and shorter periods of inundation.

Regardless of the form that architecture for flooding undertakes, the multiple case-study analyses unveils that flood resilient houses must provide the continuous access to and from the structures, guaranteeing the contact between neighbors and their access to other places within the urban environment. Infrastructural systems also must remain operational during a flood, adapted to resist damage from floodwaters, or be complemented by the introduction of sustainable systems. Finally, all the examples analyzed have proven that a more holistic approach to flooding is required, defining new relationships between rising tides and the built environment. These are expressed and consolidated through the application of specific materials, technologies, and sometimes interchangeable functions, combined to create alternative means for users to inhabit flood-prone zones and to perceive their transient natural environments through built form.

Allowing for the temporary and recurrent presence of water in any housing development requires more than the design of houses strong enough to physically withstand floods. The implementation of the analyzed residential communities asks inhabitants to adopt a more flexible existence, one that accepts that during a flood their daily lives will be sustained, but will be altered to some extent. As the examples show, architects can implement design strategies to instigate new perspectives for living with water, offering secure, and most of the time inspiring, living conditions before, during, and after a flood. The adoption of specific materials and methods of construction serve as a constant
reminder of flood hazard. The implementation of sustainable features enhanced by their prominent role in the design, altogether with a closer contact between inhabitants and their surrounding waters, can certainly induce a higher sense of environmental stewardship.

The case studies analyzed also point to the fact that flood resilience must be pursued at various scales. Designing at the scale of the house enables one to create structures capable of physically withstanding the pressures exerted by rising waters. Working at the neighborhood scale allows for architects and urban designers to conceptualize systems able to maintain a community functioning, from the provision of water and electricity, to access to spaces for working, shopping, and leisure. Furthermore, designing at this larger scale allows for the incorporation of landscape elements such as streetscapes, parks, and gardens, creating unique spaces for community interaction, at the same time minimizing water runoff and protecting contiguous urban areas from the hazard of floods. Finally, designing at a regional scale allows for planners to envision hard-infrastructure projects to be applied in combination with such smaller-scale interventions, protecting these and other areas from the risk of future flooding.

The implementation of strategies at multiple scales is contingent to well integrated planning regulations and building codes. If local authorities permit residential zones in areas at risk from flooding, building codes must be flexible enough to allow for responsive development. Simply lifting all structures above the Base Flood Elevation shouldn’t be considered as the only alternative for the urban form. Keeping structures elevated from the water’s level doesn’t necessarily lead to poor urban environments, but when each house is designed in isolation, with all structures raised above ground level in the same neighborhood, a quasi-infinite layer of unused ground floor is established. Physical connections between inhabitants and their neighbors are restricted, while visual connections between the inside and outside of the housing structures are diminished. The New Orleans’ case studies, which exemplify one of such urban environments, weren’t designed to remain occupied during a flood and the structures are safeguarded against damage, characteristics that respond not only to a flood-, as to a hurricane-prone condition. The question that remains unanswered is: what will happen to the neighborhood most of the time, when it sustains normal weather conditions, if its
structures are designed only to respond to extreme climate events?

Some of the answers for the provision of design regulations better suited to such transient conditions can be found in the United Kingdom’s guidance presented in Chapter 6. Focusing on the concept of a resilient architecture, rather than solely on that of resistance, the guidance suggests multiple strategies to be applied in accordance to specific site conditions, defining structures not only able to withstand the pressures caused by rising waters, but also capable of creating unique urban environments able to creatively adapt to both ‘dry’ and ‘wet’ settings.

In order to instigate changes in building codes and planning regulations, architects must continue to work on design alternatives that can be tested in order to challenge and alter the regulations that currently define development in the floodplain. Solutions that address both current regulations and additional measures, such as those implemented by Morphosis’s “Float House,” seem to be ideal to this end.

Although flooding has become a global phenomenon, it requires contextualized solutions. Flooding assumes different forms and produces diverse impacts in each community it comes upon. Hence, flood resilience can only be achieved through locally oriented strategies. These however can be informed by approaches tested elsewhere. This thesis offers a set of principles to be incorporated in the design of houses for zones prone to flooding. Additionally, it serves a catalog for tested and untested design solutions able to inspire architects, urban designers, and policy makers to embrace the challenges of working with water, incorporating it as an agent in the production of space, and generating unique built forms to house communities in any given floodplain.

While this thesis investigates architectural responses to flooding in the form of new urban development, the necessity of adapting existing urban settlements to rising waters persists, offering a unique challenge to achieve resilience. The thesis is also limited to the case studies analyzed, selected because they represent contemporary technical solutions following current urban patterns and for their availability in the literature in English. Nonetheless, this research has set a framework for analysis that can certainly be complemented by future research. Further studies must be conducted in communities
that have traditionally coped with the presence of water and on new developments taking place on zones prone to flooding in different regions across the globe. Such studies must become part of an interdisciplinary approach, complemented by several perspectives, in search for multiple solutions from an architectonic, engineering, regional and city planning, and ecological standpoint.

One of the biggest challenges of the architecture profession is to adapt the built environment to future climate conditions. This is a challenge that must undertaken if buildings and cities are to be designed not only to physically withstand these imminent pressures, but above all to create places for communities to live and thrive.
## APPENDIX PROJECT MATRIX

<table>
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<th>Project Name</th>
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### Architectural Elements Breakdown:

- Site
- Structure
- Skin
- Program
- Infrastructure
- Furniture
- Policy Challenges

### Exploded 3D Diagram

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**HOUSE 1: Amphibious Unit, Implementation Barendrecht**  
Barendrecht, South Holland, NL

| SITE | - Plots are not defined  
- Buildings float freely, as part of an evolving landscape |
| --- | --- |
| STRUCTURE | - Floating Platform  
- Grid Structure  
- Pre-fabricated |
| SKIN | - The building has two skins  
- The outer skin can be completely opened, enhancing the connection between inhabitants and water  
- The inner skin is built as a traditional facade  
- Lightweight materials |
| PROGRAM | - The double skin surrounds the house, creating a buffer zone for privacy  
- The usable roof guarantees user’s continuous access to an open green space |
| INFRASTRUCTURE | - Self-sufficient unit: energy is harvested from the sun and stored in batteries, water is collected from the rain and filtered to be used in the sink and on the toilets, and the sewage is treated in a composting system |
| FURNITURE | -- |
| POLICY CHALLENGES | - The house is not located on a defined plot, challenging the idea of individual property |
AMPHIBIOUS UNIT
Barendrecht, NL

INFRASTRUCTURE
Water/ Solar Power Collection System

PROGRAM
Green Roof

STRUCTURE
Floating Base

SKIN
Outer Shutters
## HOUSE 2: Floating Flop, Implementation Rotterdam–IJsselmonde
Rotterdam–IJsselmonde, South Holland, NL

| SITE | - Three cells: living container, ecological garden, and amphibious open space, arranged in varied ways, configure the urban setting.  
- Floating pathways connect the units  
- Pumps control water overflow  
- Houses are anchored in place |
|---|---|
| STRUCTURE | - Floating base on permanently “wet” site  
- “U” shaped shell structures individual cells  
- The paths are structured independently from the housing cells |
| SKIN | - The composition of each cell’s skin relates to the level of privacy of its inner program  
- Some cells are opened to below, enhancing the contact of the inhabitant with the surrounding environment |
| PROGRAM | - Each cell has its own program  
- The combination of different cells conform the house |
| INFRASTRUCTURE | - Floating pathways carry infrastructure  
- Each unit presents a filtering tank  
- Water gardens purify the water of the polder system |
| FURNITURE | |
| POLICY CHALLENGES | - Fire Codes might limit the “openness” of the cells due to the proximity to other houses |
FLOATING FLOP
Rotterdam-IJsselmonde, NL

STRUCTURE
‘U’-Shape Shell
Floating Base

PROGRAM
Floating Living Container

SKIN
Variable Materials/ Opacity

INFRASTRUCTURE
Traditional Systems
Embedded on Pathways
HOUSE 3: Floating Module, Implementation Gouda
Gouda, South Holland, NL

SITE
- The house don’t have a defined position
- Houses are to be kept 10 meters apart, unless otherwise allowed by the contiguous neighbor
- The unit is accessed by car/truck when the soil is marshy and by boat/amphibious vehicle, during a flood

STRUCTURE
- Pre-fabricated 40m2 modules
- Modules can be connected/disconnected guaranteeing future flexibility for the housing units
- 4 cores, 2 structural and 2 non-structural (placed in diagonal), compose the houses

SKIN
- Flexible skin: the level of openness is initially defined by the level of privacy required by its inner program, changing according to season

PROGRAM
- Varies according to user needs (each housing unit can be composed by a different number of modules)

INFRASTRUCTURE
- Self-sustaining (specific features not identified)

FURNITURE
- 

POLICY CHALLENGES
- Houses are not considered real state (they are developed as boats)
FLOATING MODULE
Gouda, NL

INFRASTRUCTURE
Solar Panels

SKIN
 Operable Walls/ Skylights

PROGRAM
Floating Module

STRUCTURE
Floating Base
HOUSE 4: Turnaround House
London, UK

SITE
- Located on a flood plain with Base Flood Elevation at 600 mm (2ft)
- Static structure surrounded by gabion walls that prevent the entrance of debris
- Elevated gardens run adjacent to the houses main-facade, and are connected during the flood, maintaining access to the houses

STRUCTURE
- Traditional wet-proof structure
- Crawl space controls small floods

SKIN
- A concrete dado rises from the foundation, extending beyond the BFE. Materials below BFE are durable and flood damage proof
- Operable skylights are designed to expedite the drying process
- Timber shutters in the main facade fold down connecting elevated gardens

PROGRAM
- In the event of a flood, the house's ground-floor program is relocated upstairs, allowing floodwaters to occupy the house's ground level

INFRASTRUCTURE
- Electrical components located above BFE
- Water provision: potable water storage, water tank above bathrooms

FURNITURE
- Several storage spaces are designed throughout the house (second floor slab, staircase, and central wall)

POLICY CHALLENGES
- None according to UK standards
TURNAROUND HOUSE
Floodplain, UK

FURNITURE
- Grand Storage Wall

SKIN
- Variable Materials adopted according to proximity with water

INFRASTRUCTURE
- Water Storage System

PROGRAM
- Relocation of Activities to the Upper Floor during a flood

STRUCTURE
- Concrete Dado
HOUSE 5: Eleena Jamil Architects’ House
London, UK

SITE

- Static Structure
- The topography was manipulated to keep the ground floor partially dry during a flood
- Houses part of a comprehensive water management system for the neighborhood
- An elevated pathway, connecting the houses’ second floor provide a escape route

STRUCTURE

- Brick structure resistant to water
- Water is allowed to partially enter the ground floor

SKIN

- Elevated door thresholds keep low flood waters out of the structure
- Resilient materials were adopted in areas of the house in which floodwaters are allowed to enter

PROGRAM

- The house presents multiple elevated open spaces, with different levels of privacy (ground-floor courtyard, second floor elevated green space, and elevated backyard)
- The kitchen was located on the rear elevated portion of the ground floor, protecting appliances from floodwaters

INFRASTRUCTURE

- Permeable surfaces, applied throughout the scheme, slow down water run-off

FURNITURE

- —

POLICY CHALLENGES

- None according to UK standards
ELEENA JAMIL ARCHITECTS’ HOUSE
Floodplain, UK

INFRASTRUCTURE
- Elevated Pathway

PROGRAM
- Open Green Spaces

SKIN
- Resilient Materials on the Ground Level

STRUCTURE
- Traditional Structure with Engineered Brick Foundation

SITE
- Terrain Cut and Fill
**HOUSE 6: Pohkit Goh’s House**  
**London, UK**

| SITE | - Static Structure  
- The house is kept dry in floods up to 0.6 meters  
- Gardens and planted swales control water flows during and after a flood |

| STRUCTURE | - White concrete shapes the house’s ground floor, offering resistance in the face of higher floods |

| SKIN | - White concrete on the ground floor  
- A ‘glass-box’ constitutes the second floor, covered by vertical wooden elements, which control solar gain and the level of privacy within the unit |

| PROGRAM | - Elevated open spaces located adjacent to the house increase the inhabitant’s level of privacy |

| INFRASTRUCTURE | - Traditional Infrastructure Provision |

| FURNITURE | -- |

| POLICY CHALLENGES | - None according to UK standards |
POHKIT GOH’S HOUSE
Floodplain, UK

SKIN
Wood and Glass ‘Box’

STRUCTURE
Concrete Base

PROGRAM
Open Elevated
Green Spaces

SITE
Terrain Cut and Fill
HOUSE 7: Hopper Howe Sadler’s House
London, UK

SITE
- Sloped site adjacent to water body
- An elevated platform located around the house and attached to the pontoon brings users closer to the water

STRUCTURE
- Concrete pontoon attached to columns ‘floats’ in place
- Upper pre-fabricated structure

SKIN
- Steel box (shipping container aesthetic)
- High windows bring light to the partially sunken ground floor
- Large windows open to the view on the second floor

PROGRAM
- Partially sunken ‘sleeping’ areas guarantee privacy to the users
- Outdoor open space ‘floats’ with the house

INFRASTRUCTURE
- Traditional infrastructure provision
- Partially sunken down level thermally insulated

FURNITURE
- –

POLICY CHALLENGES
- None according to UK standards
HOPPER HOWE SADLER'S HOUSE
Floodplain, UK

SKIN
Steel and Glass pre-fabricated elements

STRUCTURE
Concrete Pontoon cast in situ

PROGRAM
Partially Sunken Ground Level, connected with an open Green Space

SITE
Sloped Riverine Terrain
HOUSE 8: Aqueous Neighborhood, New Aqueous City
New York, US

SITE
- Site on the water
- Static structure
- Floating pathways connect the building to the main land

STRUCTURE
- Horizontal bridge structure supports the multi-family housing building blocks
- Vertical structure, built on stilts, houses elevators and stairs, and supports the horizontal bridge
- Each building has its own structure, which connects to the shared bridge structure

SKIN
- Lightweight materials
- Traditional street image is maintained

PROGRAM
- Shared green space on the rooftop functions as shared open space to which all the buildings are connected, also working as a rescue area in the event of a hurricane

INFRASTRUCTURE
- Individual homes: micro anaerobic digesters
- Treatment for solid waste and production of natural gas to be used at the units
- Entire System: floating treatment wetland

FURNITURE
--

POLICY CHALLENGES
- The shared bridge structure is to be provided by the city
AQUEOUS NEIGHBORHOOD
New York, US

PROGRAM
Shared Green Space

SKIN
Each Unit presents its own facade composition

STRUCTURE
“I” Shape Steel Bridge resting on Stilts

INFRASTRUCTURE
Floating Treatment Wetlands
HOUSE 9: Two-Bay Shotgun
New Orleans, US

SITE
- Water enters and flows freely on the predetermined site
- Static structure
- Extending the facade to ground level acts as a filter for debris
- Houses become isolated during a flood

STRUCTURE
- House sits on stilts 1.5 to 2.5 meters above ground level
- Structure: concrete pillars on ground floor, other materials on the second floor

SKIN
- Roof merges with facades to create a high-performance surface able to maintain the house’s inner temperature, acting as a constant reminder for the houses’ sustainable features

PROGRAM
- Porch space in the front and rear portions of the house connects inhabitants visually and physically to the neighborhood

INFRASTRUCTURE
- Rainwater collection, energy harvested from the sun, controlled temperature variations, geothermal systems, passive ventilation
- Not completely self-sustaining, still connected to the grid (sewer and potable water)

FURNITURE
- Shigeru Ban’s design proposes structural furniture modules, increasing storage and open floor space, besides acting as thermal barrier

POLICY CHALLENGES
- Complies with national and local building codes, and “Make It Right” guidelines
TWO–BAY SHOTGUN
New Orleans, US

INFRASTRUCTURE
Upper windows—cross ventilation
Ground Floor Cistern - Rain water collection system
Solar Panels

SKIN
Roof and facades merged into one element

SPECIAL ELEMENT
Safe area for rescue in the attic

PROGRAM
Porch space reminiscent of New Orleans' traditional houses

STRUCTURE
Second floor resting on stilts, elevated above the ground level
HOUSE 10: Four-Bay Shotgun
New Orleans, US

SITE
- Water enters and flows freely on the predetermined site
- Static structure
- Houses become isolated during a flood

STRUCTURE
- House sits on stilts 1.5 to 2.5 meters above ground level
- Structure: concrete pillars on ground floor, other materials on the second floor

SKIN
- EDR: Customizable hurricane shutters

PROGRAM
- Besides front/back porch space, multiple elevated open spaces are proposed in each model home, working as a safe haven during a flood

INFRASTRUCTURE
- Rainwater collection, energy harvested from the sun, controlled temperature variations, geothermal systems, passive ventilation
  - Not completely self-sustaining, still connected to the grid (sewer and potable water)

FURNITURE
- 

POLICY CHALLENGES
- Complies with national and local building codes, and “Make It Right” guidelines
FOUR-BAY SHOTGUN
New Orleans, US

INFRASTRUCTURE
Rainwater/ Solar Power harvesting systems
Ground Floor Cistern

SKIN
The design allows for the customization of the facade

PROGRAM
Stairs with areas for “stoop-sitting”

STRUCTURE
Second floor resting on stilts, elevated above the ground level
HOUSE 11: Float House
New Orleans, US

SITE
- Water enters and flows freely on the predetermined site, with the entire structure rising together with variations on the level of the water
- Structure floats in place
- House becomes isolated during a flood

STRUCTURE
- Concrete base cast in situ connected to poles prevents the structure from drifting laterally
- Expanded Polystyrene floating chassis to which the house and all its appliances are connected

SKIN
- Shell made of efficient materials, structurally insulated
- Windows protected by operable hurricane shutters

PROGRAM
- Porch space in the front portion of the house, raised only 1 meter from ground level, connects inhabitants visually and physically to the neighborhood

INFRASTRUCTURE
- Chassis generates and sustains its water and energy needs
- Not completely self-sustaining, still connected to the grid (sewer)

FURNITURE

POLICY CHALLENGES
- Complies with national and local building codes, and “Make It Right” guidelines
FLOAT HOUSE
New Orleans, US

PROGRAM
“Two-Bay Shotgun” floor plan arrangement

SKIN
The shell: prefabricated skin with operable hurricane shutters

INFRASTRUCTURE
The chassis: prefabricated base to which all sustainable features (Rain water/ Solar power harvesting systems, geothermal system) are connected

STRUCTURE
Concrete foundation cast in situ, supports guiding poles that prevent the house from moving laterally
## HOUSE 12: Adaptable Multi-Family Typology
New Orleans, US

### SITE
- Water enters and flows freely on the predetermined site
- Static structure
- Houses become isolated during a flood

### STRUCTURE
- House rests on stilts 1.5 to 2.5 meters above ground level
- Structure: concrete pillars on ground floor, other materials on the second floor
- Bild Design’s house: split level structure with half of the built area located closer to the ground level

### SKIN

### PROGRAM
- Houses divided in two sections that can be combined into different configurations: single family, two families, tenant/rental, and residential/business
- Gehry’s Partners: multiple floors provide multiple open spaces (varandas)

### INFRASTRUCTURE
- Rainwater collection, energy harvested from the sun, controlled temperature variations, geothermal systems, passive ventilation
- Not completely self-sustaining, still connected to the grid (sewer and potable water)

### FURNITURE

### POLICY CHALLENGES
- Complies with national and local building codes, and “Make It Right” guidelines
ADAPTABLE MULTI-FAMILY HOUSE
New Orleans, US

MIRRORED SECTIONS
Atelier Hitoshi Abe

MISMATCHED SECTIONS
Bild Design, Waggonner & Ball Architects

SECTIONS WITH MULTIPLE FLOORS
Gehry Partners

INFRASTRUCTURE
Rainwater/ Solar Power harvesting systems

PROGRAM
The houses are composed by two different sections and their arrangement defines specific characteristics for each design

STRUCTURE
Second floor resting on stilts, elevated above the ground level
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