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Building Resilience through Flood Risk Reduction: The Benefits of Amphibious Foundation Retrofits to Heritage Structures

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ABSTRACT

Today, many older coastal, riverine, and deltaic communities are faced with increasing flood risk, often combined with a rise in sea levels or land erosion. Until now, the options available to owners of heritage properties have been limited. Buoyant foundation retrofits offer under-resourced communities a viable and affordable adaptation alternative to buy-outs, tear-downs, and “displacement by climate change”. Amphibious strategies will not solve all challenges related to the increased impacts of climate change on heritage architecture, but offer a resilient option for communities to protect their physical history and cultural identity. This paper will provide an overview of amphibious retrofit construction and its application to the preservation of historic buildings and neighborhoods. It will provide several case study examples, namely, retrofits of heritage buildings in the historically significant African-American community of Princeville, North Carolina; for a low-income neighborhood of freedman’s cottages in Charleston, South Carolina; and a creative approach for amphibiating architect Ludwig Mies van der Rohe’s iconic Farnsworth House in Plano, Illinois. It will connect to larger themes of developing innovative and practical methods for providing flood protection to heritage structures, using an approach that emphasizes sensitivity and adaptability to the cultural values of existing communities.

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Amphibious architecture; buoyant foundation retrofit construction; Charleston South Carolina; climate change adaptation; cultural heritage protection; Farnsworth House; flood risk reduction; freedman’s cottage; historic preservation; Princeville North Carolina

1. Introduction

In the face of climate change, historic communities are becoming more vulnerable to increasingly frequent flood and storm events. The increasing occurrence of extreme events causes repetitive loss and a need for costly rebuilding. Often rebuilding does not address the conditions of future higher water levels in flood events. Adapting to changing water levels requires forward-looking strategies to limit the disastrous impact of heavy rains and intense storms on the well-being and cultural heritage of these flood-prone communities. Successful risk reduction strategies for heritage structures require a level of cultural sensitivity and adaptability that is usually lacking in conventional flood mitigation approaches that rely on permanent static elevation. Resilient solutions capable of adapting to unpredictable future flood levels are needed, especially in our current state of climate uncertainty.

Amphibious architecture is one such solution. We argue here, with the support of three case studies, for an innovative, low-impact approach to flood damage reduction. Retrofitting the foundation structures of existing buildings with buoyant foundations enables the enhancement of community and cultural resilience in the face of flooding and climate change, utilizing a flood mitigation strategy that is both sustainable and affordable (English 2009). A buoyant foundation retrofit is a type of amphibious foundation system that allows a building to continue to rest on the ground, with little or no change in appearance, until the event of a flood. As the water level rises, such a building can float on the surface of the flood, and then lower back exactly into place on its original foundation as the flood water recedes. In environmentally and historically sensitive locations, buoyant foundation retrofits offer a strategy for sitting lightly on the land and living with the flooding, by providing temporary elevation as needed when flooding occurs. It is an entirely passive system that works in synchrony with natural cycles of flooding, allowing water to flow where it will rather than attempting to control it (English, Klink, and Turner 2016; Mohamad, Nekooie, and Ismail 2012).

It must be clearly understood that buoyant foundation retrofits are not a universal solution to flood risk reduction. In theory, any structure that can be permanently elevated is capable of being amphibiated; however, at this early stage in the development of this new technology, we would not at present consider all flood-endangered

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uarc.

heritage buildings to be good candidates for amphibiation. Rather, the technique as currently developed is proposed for application to fairly small structures constructed of relatively light-weight materials, preferably with an existing foundation system that is pier-and-beam construction or something similar with a crawl space beneath the ground floor. As such, this strategy may be more readily applicable in parts of the world such as North America or Asia, or in rural areas, rather than in the majority of heritage European cities with predominantly masonry construction.

A retrofitted buoyant foundation has three basic components: the buoyancy elements that displace water to cause the building to float above the water's surface, the vertical guidance posts (VGPs) that restrict horizontal movement so that the building can move up and down but not float away, and a new structural subframe installed beneath the existing floor framing system to support and stabilize the building while connecting it to the buoyancy elements and vertical guidance posts (Figure 1).

The visual and spatial relationship between the building and the ground is preserved by placing the buoyancy elements either above or just below ground level, as called for depending on the specific site and context. The vertical guidance posts may be configured to telescope out of the ground and/or placed in visually unobtrusive locations to minimize their visual impact. A buoyant foundation retrofit offers a strategy for sitting lightly on the land, where permanent static elevation would significantly compromise the appearance of an historic structure and may also produce unacceptable voids at street level. An amphibiated structure provides greater protection against future higher flood levels than can permanent static elevation at a fixed height (English, Klink, and Turner 2016).

Amphibious architecture has a long history of being incorporated into vernacular building techniques throughout the world, as illustrated in Figure 2. Vernacular amphibious foundation systems have also been developed over the last forty years by the residents of Old River Landing, Louisiana, where buoyancy elements formed of blocks of expanded polystyrene and steel pipe vertical guidance posts recycled from local oil industry cast-offs have been used to amphibiate homes in this flood-prone recreational fishing community (English 2009). Amphibious architecture has been explored in New Orleans, the Netherlands, the UK, Bangladesh and Thailand (English, Klink, and Turner 2016), and more recently in Poland, India, Vietnam, Canada and two more locations in Bangladesh; however, most of these projects are entirely new construction. The retrofit system developed by the Buoyant Foundation Project (BFP) offers a strategy that can be applied to pre-existing structures to preserve cultural history as represented by singular buildings, such as the Farnsworth House, or by multiple buildings in a community, such as Princeville, North Carolina, or Charleston, South Carolina. While the three case studies in this paper explore theoretical potential projects in areas of North America particularly prone to flooding, recent tests of the BFP retrofit system in the Mekong Delta, Vietnam, have demonstrated the capacity of this technology to withstand severe flooding

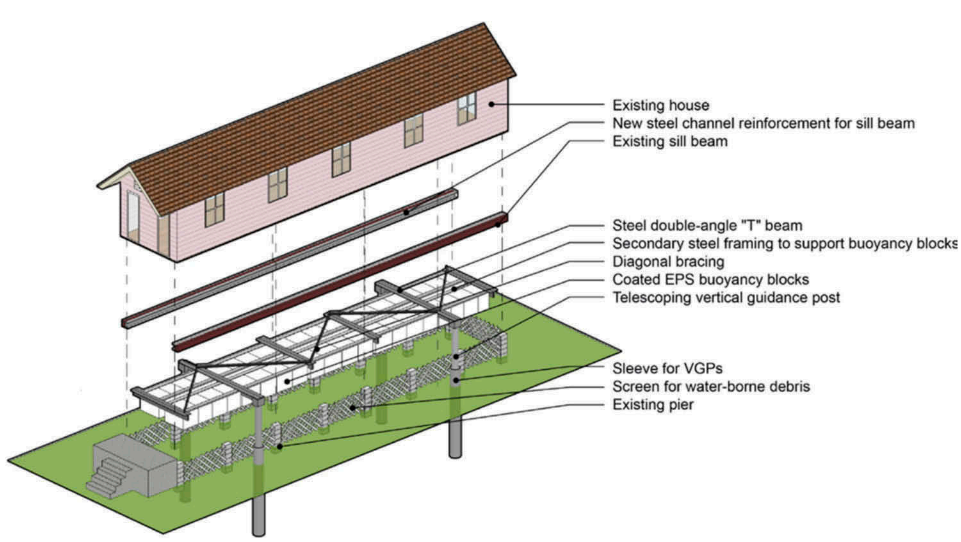

Figure 1. Exploded axonometric drawing of buoyant foundation system components, with telescopic VGPs, as designed for a Louisiana "shotgun" house (source: BFP).

Figure 2. Iraqi marsh village (left); vernacular amphibious construction in Thailand (right) (sources: National Geographic; Chuta Sinthuphan).

without compromising the cultural character of traditional vernacular housing (Buoyant Foundation Project 2018).

2. Princeville, North Carolina: case study

Princeville, North Carolina, is the oldest town in the United States incorporated by African Americans. The town was founded by freed slaves in the swamplands of the Tar River at the end of the Civil War in 1865, in the face of encouragement to return to the plantations where they had been enslaved. Resolute, they chose to remain and build themselves a town, beginning with makeshift shacks and shanties rather than give up their hard-earned freedom. Many residents of Princeville today can trace their ancestry to the town's founders. This historic town sits in the floodplain of the Tar River and has twice in the past twenty years been devastated by "100-year" hurricane-related flooding. After Hurricane Floyd in 1999, President Bill Clinton initiated an effort to expand and improve the town's levee by Executive Order but the improvements were never put into effect. More recently in 2016, Hurricane Matthew put 80 percent of the town under water (Freeman 2018; Kay 2018).

Buoyant foundation retrofits of Princeville's important historic and cultural landmarks would provide visually-unobtrusive protection from flood damage, and prevent the forced relocation of this culturally vibrant and historically significant African-American community. After consultation with the community and town officials, the Buoyant Foundation Project has proposed that the Mt. Zion Primitive Baptist Church, several significant historic homes, and the Princeville Heritage Museum be retrofitted with amphibious foundations to prevent future flood damage to the town's important markers of cultural heritage.

The Primitive Baptist Church was constructed over a 100 years ago, and was the first church built in this culturally significant town (Figure 3). The museum is housed in what was the first school in Princeville. These buildings hold Princeville's heritage and legacy (Freeman 2018). Flooding in the region is a racialized issue, as the lowest-lying areas of this region are predominantly African-American while the highest areas are mostly white (Cohen 2017).

Figure 3. Mt. Zion Primitive Baptist Church in Princeville, NC (left) and a rendering of the church in a flood (right) (source: BFP (E C English, Thanh Tran)).

The amphibious retrofit design proposed for the Church includes a buoyancy system hidden underneath the building, behind the existing brick foundation wall. The guidance posts are designed to be housed inside the existing building, in sleeves located inside the four corners in order to retain its unaltered historic appearance.

Recently a proposal to expand Princeville's town boundaries and move large portions of the community to higher ground was presented by the Federal Emergency Management Agency (FEMA) and moved forward by the state of North Carolina (Truitt 2018). This process would inevitably involve strategic buy-outs, tear-downs, and at least partial displacement of an historic town of critical national significance. Amphibious construction offers an alternative to displacement from flooding for communities seeking options to accommodate in-place flood mitigation and adaptation. Buoyant foundation retrofits do not solve all problems related to the increased impacts of climate change, but offer a viable alternative and provide hope to those who feel that the cultural heritage and strength of their community would be compromised if forced to relocate. The availability of an affordable solution to prevent further flood damage is a significant step forward for communities with a history of suffering from disenfranchisement and displacement.

The catastrophic flooding events of Princeville in 1999 (Hurricane Floyd) and 2016 (Hurricane Matthew) have sparked heated conversations about the town's future. Following Hurricane Floyd, 1,000 homes were damaged or destroyed. For ten days following the event, water up to 20 feet (6.1m) deep flooded the area (Kelley 2016). Both hurricanes submerged buildings in flood water and led to repercussions that the community, and beyond, continued to feel for months after the event (Bidgood 2017; Pressley 1999). While partial levees have been built around the town, they do not provide effective protection from the most devastating storms. With climate change, sea level rise and the threat of impending flood events, many communities have considered relocation. Buoyant foundations offer an innovative solution for existing structures to protect them from flooding while preserving community character.

The Princeville Heritage Museum is also an excellent candidate for amphibious retrofit due to its historical significance and simple wooden structure with a pier-and-beam foundation. Originally a schoolhouse built as the Princeville elementary school, it was restored and reopened as the Princeville Heritage Museum and Welcome Center (Freeman 2018). Instead of elevating, moving or replacing the building, it could easily be retrofitted with a buoyant foundation to protect it from flood damage while retaining its original appearance and location.

The structure of the main Heritage Museum building would be temporarily lifted above its current foundation to install the buoyancy system and new structural frame, consisting of pre-manufactured dock floats connected to the existing building by a steel grid framing system (Figure 4). This system is concealed behind the existing foundation walls under ordinary (non-flood) conditions thus preserving the character of the building as it relates to the ground.

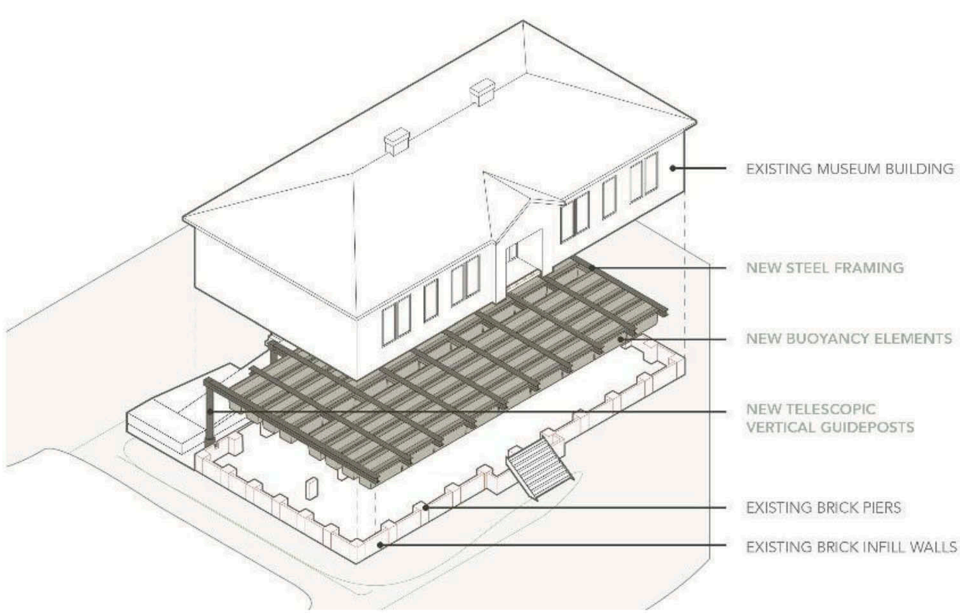

Figure 4. Exploded axonometric of the Princeville Heritage Museum (source: BFP (Teresa Tran)).

The telescopic vertical guidance posts are all located along the rear wall of the building, maintaining the visual integrity of the original front and side façades. When the buoyancy elements and steel frame are installed beneath the existing wooden floor structure and connected to the vertical guidance posts, the Heritage Museum will be able to adapt effectively to flooding conditions while maintaining its original appearance. The structures of the buildings in Princeville selected for proposed buoyant foundations are ideal candidates for retrofitting because the existing crawl spaces beneath the raised floors provide accommodation for the buoyancy elements, and thus no excavation is required.

Loss avoidance studies were conducted for a standard house and for the Heritage Museum building in Princeville to demonstrate the quantifiable benefits of amphibious retrofits. The results, previously reported (Sumanth and English 2017), show that the costs associated with a single major flooding event, comprising building repairs, loss of contents and displacement expenses, were considerably larger than the cost of a buoyant foundation retrofit by a factor that primarily depends on the depth of flooding. For the flood depth experienced in Hurricane Matthew, the loss avoidance ratio for the house was 4.68 and for the museum it was 2.2. Thus, as analyzed for a single severe flood event, the cost of installing an amphibious retrofit would be a fraction of the potential for losses due to damage and displacement, while also providing a more socially sensitive approach through the protection of property and belongings, avoidance of trauma, and the prevention of unnecessary psychological distress that accompanies loss and displacement. The affordability and reduction of damage-related expenses that buoyant foundation retrofits provide make a strong case for their use in disenfranchised, historically significant communities.

3. Charleston, South Carolina: case study

Historic coastal and riverine towns in the Carolinas are increasingly threatened by flooding. According to Spanger-Siegfried et al. (2017), even with only moderate sea level rise, many coastal US cities will experience chronic inundation by the year 2100. The City of Charleston, South Carolina, predicts that it could experience 180 days of tidal flooding by 2045 (Riley 2015). Currently, the city is grappling with how to adapt to new climate conditions and is wrestling with the options available specifically for adapting historic and vernacular architecture to accommodate the changing climate reality (Behre 2017). Forecasting 50 years into the future, Charleston has adopted an assumed increase in sea level of 1.5 ft (0.46m) for less vulnerable investment and 2.5 (0.76m) ft for emergency routes and public buildings constructed in the future (Riley 2015). The expansion of paved surfaces that accompanies the development of floodplains for housing threatens to reduce the permeability of riparian soils, creating greater volumes of run-off and exacerbating the issues of property damage and displacement associated with flood events (Darlington 2018; Haer 2012). As reported by Darlington, tensions are rising in Charleston as new floodplain developments are putting the new neighborhoods themselves at risk, along with the greater community, including the historic parts of the city and their unique housing typologies (Todd 2018). This, in conjunction with the worsening prospects of inundation due to sea level rise caused by global warming, is laying the groundwork for future flood situations to which community members will need to respond (Spanger-Siegfried et al. 2017). The city has identified three aspects of a flood resilience strategy: reinvestment in infrastructure, improved emergency response and preparedness for flood events (Riley 2015), but much of the strategy focuses on the static elevation of new construction and drainage infrastructure. Owners and residents alike need innovative tools to mitigate the exponentially increasing flooding risks.

The freedman's cottages are representative of Charleston's unique domestic architectural typology (Figure 5). These tiny structures were originally built for the working families in Charleston, often employed by their wealthier neighbors who lived in much larger and grander versions of the small vernacular cottages (Felzer 2008). Charleston has built a multi-million dollar tourism industry on the qualities of such historic buildings (Grossenbacher 2016). Today, this unique, affordable, and adaptable typology is threatened by rising sea levels and increasing storm surges brought to the Charleston peninsula by hurricanes. By 2035 neighborhoods like the Lower Peninsula with concentrations of freedman's cottages are expected to see regular and increasing chronic flooding, estimated to occur more than 26 times per year (Spanger-Siegfried, Fitzpatrick, and Dahl 2014). Even modest sea level rises would likely cause the inundation of Charleston's historic district. Since the City of Charleston has significant control over historic properties, the City must develop strategies and amendments to the Zoning Ordinance to accommodate the changing context (Grossenbacher 2016).

For these simple cottages, permanent static elevation has frequently been cited as the only practical approach. However, this solution is far from ideal as


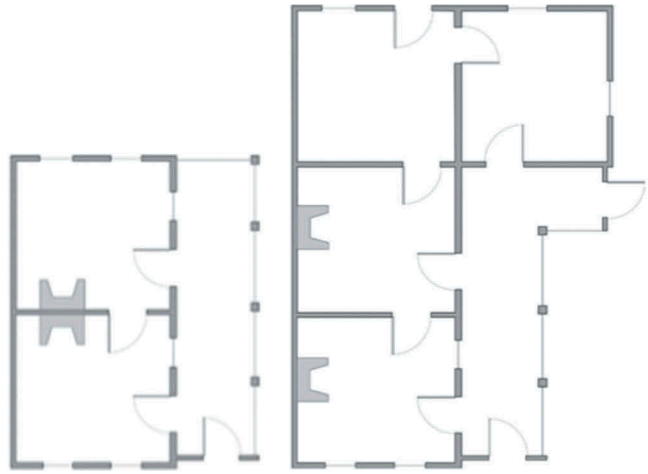

Figure 5. Traditional freedman's cottage in Charleston (left); examples of traditional freedman's cottage floor plans (center and right) (source: Felzer 2008).

it is expensive, significantly disrupts the appearance of an historic neighborhood and its traditional building typologies, and cannot easily adapt, post-installation, to increasing flood depths. The buoyant foundation retrofit approach offers a sensitive solution to vulnerable communities in the Carolinas like Charleston, and most importantly provides an economically and culturally viable alternative to under-resourced communities and neighborhoods to fight buy-outs, teardowns, and displacement from flooding.

It can be demonstrated that buoyant retrofits are easy-to-implement, inexpensive additions that offer significant cost savings in the long term, especially in the face of multiple future flood events (English, Klink, and Turner 2016; McMillan, English, and Sumanth 2017; Sumanth and English 2015; Sumanth and English 2017). This flood risk reduction strategy protects individuals and their belongings without imposing on their daily routines or changing the architectural and urban experiences these historic building types and communities provide.

Although the amphibious approach does not solve all challenges related to the increased impacts of climate change on historic and culturally significant places and properties, it does offer a means of maintaining long-standing, culturally significant relationships to place and home.

4. Farnsworth house, Plano, Illinois: case study

The Farnsworth House, designed by renowned architect Ludwig Mies van der Rohe, is an icon of domestic modernism that demonstrates a strong connection to the surrounding natural landscape. The house is set back 90 feet (27.4m) from the Fox River in the floodplain. The

Figure 6. Site plan of the Farnsworth House (source: BFP (Jason Mcmillan)).

main floor is elevated five feet (1.52m) above grade, with a clear open space between the underside of the floor slab and the ground to accommodate the 100-year flood depth that was projected at the time of its design (Figure 6). However, only three years after completion, major flooding occurred, and water entered the house to a level of two feet (0.61m) above the interior floor surface (Silman et al. 2014).

In recent years, flooding has caused significant damage to the structure and contents of the house. With the rapid spread of development along the watershed of the river, the frequency and depth of flooding have increased since its completion in 1951. Studies conducted by the National Trust for Historic Preservation and their consultants report that the frequency and intensity of flooding will continue to increase. The site is expected to flood annually with a 20 percent chance of the water levels rising above the terrace level. The National Trust for Historic Preservation has spent roughly a half million US dollars on repairing flood damage, studying the effects of flooding on the house, and investigating permanent mitigation strategies since purchasing the house in 2003 (National Trust for Historic Preservation 2018).

The National Trust has examined many different options to help protect the Farnsworth House in future flood events, including elevation, relocation, a hydraulic system and a buoyancy system (Silman et al. 2014). The prospect of relocation has been met with strong criticism, including from Mies van der Rohe's grandson, Dirk Lohan. Lohan, an architect in Chicago, says, "It was designed to be in the floodplain. In other words, the flooding was part of the concept of the house" (Murray 2015).

The Trust seeks a solution that protects the house without compromising the architect's vision of floating slabs. The BFP design competition entry, "Fibious Farnsworth", introduced an amphibious foundation system to allow the Farnsworth House to float in extreme flood scenarios, and then lower it to its original position as the water receded. This entirely passive strategy would require no human intervention during a flood. It combines appropriate, resilient technologies with a sensitivity to preserving this valuable cultural asset (English and Fonseka 2015) (Figure 7).

The 'Fibious Farnsworth project was selected as one of five finalists in the Self-Initiated Projects category and received Honorable Mention in the Historic Preservation category in the 2014 Architizer A+ Awards design competition (English, Klink, and Turner 2016). The 'Fibious Farnsworth proposal is a subtle intervention, in keeping with the house's minimal aesthetic, remaining invisible until activated by the presence of flood water. It is a simple and passive strategy, providing an effective flood mitigation alternative to relocation or the installation of a vastly more

Figure 7. The Farnsworth House in various flood conditions (source: BFP (Ting Zhang)).

expensive and complex mechanical system that would require human activation if electronic sensors failed.

The fully below-grade installation of the retrofitted amphibious foundation ensures that the outward appearance of the house remains visually unaltered. A poured-in-place concrete pit, installed below ground directly beneath the house, conceals the buoyancy assembly below the surface of the earth. A steel sub-frame installed just below the ground surface supports a matrix of buoyancy blocks wholly contained inside the pit. When flooding occurs, the buoyancy blocks displace water and emerge from the pit to lift the house. Utilities are fitted with flexible lines that pass through the same sleeve currently carrying the existing utility lines.

The amphibious design replaces the house's conventional concrete footings with sleeves that accommodate sliding vertical guidance posts. These posts are extensions of the house's existing wide-flange columns, reaching 13–15 feet (4.0-4.6m) below the surface of the ground. They allow the house to rise and fall during a flood while restricting its lateral movement. The proposal offers an alternative to the costly restoration that is required after each flood while preserving the aesthetic qualities of the Farnsworth House and maintaining its carefully established existing site relationships.

5. Conclusions

Buoyant foundation retrofits are an innovative and culturally sensitive approach to historic preservation for flood-prone buildings. As flooding from rising sea levels and increased storm activity continues to pose greater threats to vulnerable communities and historic sites, it is imperative that appropriate resilience strategies are implemented. As is demonstrated through the proposed retrofits to historic community buildings and homes in Princeville and Charleston, and the amphibious retrofit proposed for the Farnsworth House, it is clear that buoyant foundations are a solution that allows heritage buildings to remain in their original settings and preserves their cultural significance, while protecting them from flood damage.

Disclosure statement

No potential conflict of interest was reported by the authors.

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