Socioeconomic Vulnerabilities and Housing Reconstruction in Puerto Rico After Hurricanes Irma and Maria

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Abstract

Hurricanes Irma and Maria caused widespread destruction in Puerto Rico in 2017. In the absence of government recovery support and denial of assistance based on ownership, many households have engaged in a process of informal reconstruction. While informal reconstruction can provide an alternate path to recovery, its uncontrolled and unchecked nature carries inherent safety risks and ambiguous legal status. Due to the inherent uncertainties in informal housing and its known consequences, it is important to identify households that may be more likely to engage in informal reconstruction, to promote and support safe building practices and access to resources. This is especially important in a context where informality is often seen as ‘inevitable.’ Socioeconomic vulnerability is a useful framework to understand these trends as vulnerability can restrict a household’s ability to engage with the formal construction sector, encouraging those households to pursue other methods of recovery. This study aims to understand the individual and compounding effects of socioeconomic vulnerabilities on household use of informal reconstruction. Data collection includes household surveys ($N=305$) in the municipalities of Loíza and Yabucoa in Puerto Rico. Results suggest that socioeconomic vulnerabilities work in a compounding manner affecting household decisions to use informal reconstruction; specifically, a compounding effect exists in the combination of the absence of ownership documents and unemployment. Results from this study can inform housing recovery programs to identify households that are more likely to engage in informal housing reconstruction and ensure they receive the right support and resources to promote safe recovery.

Keywords Socioeconomic vulnerability · Informal housing reconstruction · Disaster recovery · Puerto Rico

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1 Introduction

Hurricane Maria, a category 4 storm, devastated Puerto Rico late September 2017, just 10 days after the destructive Hurricane Irma had made landfall. This paper focuses specifically on the recovery and reconstruction phase, which follow the immediate emergency response. One of the most critical aspects of long-term recovery is effective and equitable reconstruction of damaged and destroyed housing. In Puerto Rico, roughly one-third of homes needed reconstruction or repair, totaling roughly 400,000 homes (Brown 2018). Housing reconstruction immediately became critical for long-term recovery. However, the situation became increasingly severe as recovery assistance proved inaccessible to many households. One critical factor in the process of recovery was the high rates of informal housing present in Puerto Rico before the Hurricanes. Informal housing in Puerto Rico includes ‘homes that have been self-built, without ownership over the land, without building permits or without following building codes’ (Algoed and Hernandez Torrales 2019). Informal housing was a complicating factor to the recovery process because the locations of informal homes are not officially documented, reducing accuracy in population estimates and locations of residents that may need assistance after an emergency event. Further, there is often little to no record of the physical conditions of the houses, potentially dangerous because they may have not been built to code and often contain incremental building practices with additions being made over time that can stress the structural integrity of the home. In addition, informal housing can be more susceptible to damage because it may not have been built to safety standards and is often found in locations prone to frequent flooding (Hinojosa and Meléndez 2018). Aforementioned policy that potentially marginalizes vulnerable populations have contributed to vulnerable populations being left without long-term housing, increasing their susceptibility to health and safety risks and contributing to growing mental health issues throughout Puerto Rico (Acevedo and Pacheco 2018; Dickerson 2017). Estimates suggest that up to 55% of housing in Puerto Rico before Hurricane Maria could be categorized as informal, with numbers anywhere between 260,000 and 700,000 informal houses in Puerto Rico (Acevedo 2019). Furthermore, the overseeing regulator in post-disaster recovery in Puerto Rico is the US federal government, whose policies for distributing financial resources for housing reconstruction to households exclude, both directly and indirectly, informal housing residents. These policies subsequently exclude hundreds of thousands of informal homes from financial assistance (Robles 2018; Viglucci 2018); financial support which, for some, represents the only option for paying the high costs associated with reconstruction. The US Housing Department (HUD) is the official authority in the distribution of reconstruction funds in Puerto Rico after Irma and Maria, through the Community Development Block Grant-Disaster Recovery (CDBG-DR). Billions in funds have been allocated to Puerto Rico to fund the housing reconstruction effort, and within this the CDBG-DR action plan explicitly identifies reducing the existence of informal housing as a key goal. While the action plan acknowledges the symbolism in informal housing of the resilience of the Puerto Rican people, it also acknowledges the safety issues and vulnerability associated with having such a large stock of informal housing in times of disaster. However, the action plan is limited in its direction for how to approach the complicated reality of informal housing, and references only a handful of forces at play, such as high rates of unemployment and an aging population. If we are to move toward holistic recovery efforts that can effectively operate within complicated and nuanced systems of housing types and reconstruction methods, there is additional study needed in the contextual nature of informal housing in Puerto

Rico. This includes characteristics of households and underlying processes at play that have created the existing housing stock throughout Puerto Rico. This study aims to provide a more detailed understanding of the complex reality of informal housing across the Archipelago.

Informal housing construction is often seen in low-income neighborhoods (Algoed and Hernandez Torrales 2019; Harris 2018; Ward 2014), who will likely have less resources to obtain a title to the land and house, hire an engineer or architect, obtain building permits, or follow building codes. Further socioeconomic vulnerabilities have been shown to increase the potential for residing in informal housing, such as language barriers with the established legal system and limited education, affecting their ability to navigate the processes and paperwork associated with reconstruction and communicate with the personnel (Way 2009). Socioeconomic vulnerability in this context is defined as a household's economic or social characteristics that cause exclusion from housing reconstruction resources or acceptance to reconstruction programs or decision-making power and agency after a disaster event due to marginalization (Hamideh 2020; Hamideh et al. 2018; Hamideh and Rongerude 2018; Wisner et al. 2004). Informal housing can be a polarizing recovery outcome as it creates tension between top-down and bottom-up realities. On the one hand, regulating authorities in Puerto Rico and international NGOs have been vocal about the goals to 'manage' and reduce the occurrence of informal housing in the post-Maria recovery process (Government of Puerto Rico, Department of Housing 2018; Resilient Puerto Rico Advisory Commission 2018). On the other hand, while there are significant risks associated with informal housing, it can also be a cost-effective, time-efficient means of reconstruction which enables homeowner agency and control over their own recovery (Harris 2018). Informal housing provides low-cost housing options in the locations where housing is most needed (Wegmann and Mawhorter 2017). This is especially important in areas where affordable housing provided by the state is insufficient (Zhao 2017). From a community perspective, informal housing also enhances social stability, as it increases a feeling of belonging and permanence within a community (Soliman 1996). Informal housing can also provide economic opportunity, as in some cases, informal housing in urban areas is the first step toward residing in an urban area with employment opportunities, toward eventually securing a more formal home (Soliman 1996). Further, informal homes are often built on land that an individual already owns and is rented out to provide extra income from an asset that is already owned (Zhao 2017).

Some communities and local organizations find that informal housing reconstruction is the only method of achieving recovery, and have supported informal housing reconstruction as an alternative to living in unsafe conditions or migrating away from one's community and established networks (Acevedo 2019; Acevedo and Pacheco 2018). Informal housing has been a large part of housing stock in Puerto Rico historically and has been a powerful method of self-organizing housing construction and a tenure system (Fuller Marvel 2008). Therefore, there is inherent conflict between long-standing informal housing practices and the disaster policy by the federal government, creating explicit tensions evident in housing reconstruction after Hurricane Maria.

Informal housing is a complex yet understudied phenomenon. It is expected that socioeconomic vulnerability will play a critical role in determining a household's use of informal housing reconstruction because those with limited resources would lack the capacity to build formally for example through hiring engineers and navigating the process of acquiring building permits. Specifically in Puerto Rico, lack of ownership documents in the form of legal property titles can add to a household's vulnerability. Houses without titles suffer from disqualification from financial resources for reconstruction, potentially imminent

eviction, and inability to legally sell their home (Kimmelman and Gregory 2019; Viglucchi 2018; Way 2009).

Thus, this research asks the question, ‘What compounding roles do socioeconomic vulnerabilities play in household decisions to use informal housing reconstruction post-Hurricane Maria in rural Puerto Rican communities?’ Data collection includes door-to-door surveys ($N=305$) in two rural communities of Puerto Rico, 15 months after Hurricane Maria. Survey questions included information about households’ socioeconomic vulnerabilities and their use of informal housing reconstruction. Logistic regression models include the dependent variable of use of informal housing reconstruction and investigate the interaction effects between the socioeconomic vulnerability indicators of age, gender, education, annual income, employment, and ownership documents pre-disaster. These interacting variables are posited as compounding variables; variables that interact in some way to change the relationship of one variable with the dependent variable, when the other variable is also present in the model (Lavrakas 2008). According to existing literature suggesting the compounding nature of vulnerability and the correlation between socioeconomic vulnerability and housing vulnerability, the authors hypothesize that increased levels of socioeconomic vulnerability will lead to increased levels of informal housing reconstruction. However, previous studies have also suggested that informal housing is much more complicated than a by-product of lack of resources or ability to reconstruct within the formal framework. For example, previous studies in Puerto Rico regarding informal housing show that households with higher rates of employment tend to engage in informal reconstruction at higher rates (Talbot et al. 2020). This is potentially due to the role of employment in forming strong social networks that can be activated to assist with reconstruction and underlines the complex nature of informal housing within this context. While socioeconomic vulnerabilities can become the basis for exclusion, the very nature of informal housing is not necessarily an alternative or sub-par option and thus the relationship between informal housing and household characteristics requires a deeper understanding.

This study is grounded in socioeconomic vulnerability theory, focusing on how social and economic structures have created potential for exclusion from access to resources and programs, whether intentional or unintentional. Exclusion in this context is defined simultaneously as a process and condition that leads to disadvantage and a systematic denial of opportunity, due to intertwined social, economic, and power inequalities (Bernt and Colini 2013). Marginalization is an extension of exclusion steeped in power imbalances and directed at defined subgroups of people (Causadias and Umaña-Taylor 2018). In the case of Puerto Rico, both exclusion and marginalization have occurred throughout the housing reconstruction process, as homeowners struggled to access resources for reconstruction in an equitable manner. For example, applications for housing financial assistance were originally only available over the phone or online; however, the return of electrical power, phone service, and internet was not the same throughout Puerto Rico, returning to urban and wealthier areas first. Those in more urban areas or with the resources, time, and money to travel or otherwise find access to communication, found themselves at an advantage in starting their recovery process. In extension, in a disaster context, socioeconomic vulnerability refers to household’s economic or social characteristics that can become the basis of exclusion and marginalization from housing reconstruction resources, or limitations to decision-making power and agency after a disaster event (Hamideh 2020; Hamideh et al. 2018; Hamideh and Rongerude 2018; Wisner et al. 2004). The socioeconomic vulnerability indicators used in this study include age, gender, education level, annual income, employment status, and owning land tenure documents. Importantly, there is a compounding nature of vulnerability, where individuals or families with multiple socioeconomic

vulnerabilities experience higher vulnerability to disaster and increased difficulties in the recovery process (Enarson et al. 2006; Hazeleger 2013). These studies suggest that overlapping vulnerabilities can have a multiplicative effect, not just additive. This research aims to extend the investigation of the compounding nature of socioeconomic vulnerability to include an indicator of housing informality pre-disaster, in the form of owning land tenure documents. This study posits housing informality as a socioeconomic vulnerability indicator, as the status of informal housing resident has been shown to create its own level of vulnerability due to stigmatization and disempowerment (Romero-Lankao et al. 2014). In the specific case of Puerto Rico, housing informality also disqualified households from financial resources for reconstruction from FEMA (Viglucchi 2018).

Theoretical implications of this study include an understanding of household decision making within the lens of informal housing. Thus, we gain a more holistic image of reconstruction activity post-disaster regarding household characteristics as well as the legal status of the structure pre-disaster.

2 Informal Housing

Informal housing exists on a global scale in both rural and urban settings and is rarely immediately identifiable as an informal structure (Harris 2018). A continuum of informality exists from large, widely identified informal settlements, to houses whose informality status is not clearly visible and can only be known by talking to the owners or seeing the documents (Harris 2018). Specifically, in Puerto Rico housing informality can look like owner-occupied land with unpermitted housing, meaning the land is owned, but there was no formal permit to begin construction. At the same time, informal housing can also be unpermitted additions or alterations to housing that was originally built formally with all necessary permissions. Additionally, informal housing can include houses that have been inherited or otherwise lack formal documentation of ownership (Resilient Puerto Rico Advisory Commission 2018). In summary, informal housing in Puerto Rico exists on a continuum and composed of many types or varying levels of informality, many of which are not visibly different from formal homes (Resilient Puerto Rico Advisory Commission 2018). At times, because of the complexity of the informality continuum, homeowners are not even aware that their house is informal. There are many drivers to building or residing in informal housing, including low levels of state regulation and enforcement of planning, low demand for formal planning, and high costs of formal construction (Briassoulis 1997).

Informal housing commonly serves vulnerable households, often because of the lower costs of construction and possibility of building without proof of formal ownership (Johnson and Lizarralde 2012; Ward 2014). Further, informal housing often occurs due to a lack of formal affordable housing in locations with job opportunities, forcing residents to seek other options (Pelling 2003). Socioeconomic vulnerabilities both make it difficult to afford formal housing, and limit access to the legal systems and processes associated with acquiring formal housing or ‘formalizing’ informal housing through reconstruction (Way 2009). Engaging in these legal systems and processes is important for reducing housing vulnerability, as it ‘legitimizes’ the housing and recognizes its permanence in regard to the law and empowers the individual in defending their right to the place (Way 2009). Specifically, the existing legal system in the USA can alienate certain households, making it impossible to secure formal land title to their homes in the following ways (Way 2009).

Barriers from language, income, education, or culture make the traditional routes to securing formal housing difficult for vulnerable residents who may not have the same legal protection or ownership status, such as undocumented immigrants (Way 2009). Further, the ability to engage with the formal processes and paperwork associated with legal housing rights create barriers against formal housing. Examples include lack of experience with the language of homeownership paperwork or ability to afford an attorney to complete a will, which make it difficult for heirs of the property to make a formal title transfer (Way 2009). At the same time, the process of ‘formalizing’ a title can be a long and expensive process, disincentivizing households who have inherited a home from going through that process (Azhar et al. 2020). The heirs problem is of specific importance in Puerto Rico, as there has been evidence since Hurricane Maria that many households in Puerto Rico had not gone through the formal process of transferring title after inheriting a house (García 2021). At that time there was no functional need for a formal title unless the owners also had a mortgage; however, often for inherited homes this was not the case (García 2021). This ambiguous ownership status has led to legal issues throughout all stages of recovery.

Additionally, informal housing can be temporary due to lack of legal recognition and documentation, creating potential for eviction (Doberstein and Stager 2013) in a moment’s notice because they do not have a legal right to the land from the perspective of the state. In summary, informal housing tends to be occupied by residents who already have moderate to high levels of socioeconomic vulnerability, such as low-income households or ethnic minorities. This is further compounded by their social and legal challenges of being an informal housing resident.

3 Post-Disaster Informal Housing Reconstruction

In a disaster context, informal housing reconstruction is often carried out using self-recovery or self-build and represents communities organizing to rebuild or repair damaged housing using their own resources (Flinn et al. 2017; Hendriks et al. 2017; Parrack et al. 2014). Informal housing reconstruction can create paths to recovery that do not exist or are difficult to access in vulnerable communities and can offer some benefits to households attempting to reconstruct after a disaster (Flinn et al. 2017; Jha 2010). For example, informal housing reconstruction allows local households to oversee the reconstruction process which can ensure that their process of housing recovery and the final outcome looks and functions according to their needs and preferences (Flinn et al. 2017; Hendriks et al. 2017). Informality also expedites the construction process resulting in shorter periods of time that households are living in unsafe conditions or emergency housing, thus expediting the return to normalcy (Flinn et al. 2017; Hendriks et al. 2017). The flexibility inherent to informal housing reconstruction can provide benefit by allowing flexible schedules and faster timelines, which can be key for vulnerable households who are also often affected by chronic health issues and decreased mobility, inhibiting their recovery process (Baker and Cormier 2015), thus. Post-disaster housing needs are severely unfulfilled, and previous studies have found that in the first year after a disaster, it is rare that more than 10% of immediate housing needs are satisfied (Parrack et al. 2014). Therefore, informal housing reconstruction can and does partially fulfill that need (Parrack et al. 2014). Informal housing reconstruction provides an option for housing recovery for households who are not able to or otherwise decide not to engage with the formal process. However, there are significant concerns resulting from this unregulated and uninspected construction.

Informal housing reconstruction poses the risk of perpetuating physical and social vulnerability to disasters due to unsafe locations or neglect of safety standards (Hinojosa and Meléndez 2018). The safety concerns often result from using unskilled labor, substandard construction methods (Flinn et al. 2017; Sakijegge et al. 2014), and building in flood-prone areas (Hinojosa and Meléndez 2018). Additionally, debris and other unsafe materials from damaged informal housing can jeopardize the safety of the surrounding community, especially if those structures are located near critical community resources such as drinking water sources (Pelling 2003). In addition to potential physical vulnerability, informal housing reconstruction also often disqualifies households from official avenues of financial assistance, such as government programs. This has been particularly pertinent in Puerto Rico, where the majority of houses have not received financial assistance from FEMA (Federal Emergency Management Agency), mainly due to the requirement of proving homeownership in the application process (Viglucchi 2018).

Without intervention it becomes difficult to turn an informal home into a formal one, according to standard policy that requires engineering plans, soil sampling, multiple site visits, permitting, and collaboration with many professionals and government agencies which can take months to years and significant sums of money. Therefore, the complication in the process of ‘formalizing’ ones home can lock homeowners into cycles of rebuilding informal housing after disaster without the ability to easily formalize. Cycles of informal housing can reinforce pre-existing vulnerabilities and perpetuate a cycle of vulnerability to disasters based on social or economic factors, such as disqualification from financial assistance from government programs, which reduces the feasibility of covering the high costs of formal reconstruction. Informal housing can also come with a social stigma that contributes to disempowerment of individual households (Romero-Lankao et al. 2014). Previous research has identified that housing type and social vulnerability affect the ability of certain groups to enact control over their recovery process and/or access resources for recovery. For example, stigmatization of public housing residents negatively influenced disaster recovery outcomes in Texas by limiting both representation and political power in recovery decision making (Hamideh and Rongerude 2018). Additionally, housing recovery after Hurricane Dolly in 2008 identified procedural disempowerment of low-income households who could not produce documentation of pre-hurricane damages. Many households were disqualified from FEMA’s IHP program because of vague definitions of damage that qualified for reconstruction funds. This procedure was seen as ‘anti-poor’ as lower-income households who had not previously repaired damages to their homes were subject to subjective decisions by damage inspectors in the Rio Grande Valley (Rivera et al. 2021). As these examples suggest, procedural vulnerability can play a central role in disempowerment within recovery, and therefore, it is likely that informal housing without land tenure documents pre-hurricanes, may carry its own layer of vulnerability in the recovery process. This may be through stigma and procedural injustice, leading to disempowerment.

4 Socioeconomic Vulnerabilities and Post-Disaster Housing Reconstruction

Vulnerability in a general sense has been defined in a disaster setting as ‘the characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard’ (Wisner et al. 2004, page 11). In other words, vulnerability is a dynamic interaction between exposure, sensitivity, and

adaptive capacity (Gallopín 2006). Vulnerability is a complex, dynamic, and multidimensional construct and must be interpreted within its local context rather than a static concept that is easily transferrable. Subsequently, different characteristics of a person or group may increase the capacity to cope with hazards in one context, while they might conversely help build such capacity in another context. In Puerto Rico, vulnerabilities of certain population groups—such as elderly, low-income, and poorly connected individuals—to Hurricane Maria impacts manifested within the context of housing recovery in the form of facing barriers due to high costs of construction, difficulties obtaining permits without extra money or connections, or time and energy that is required to go through the aid application, permitting, and reconstruction. Certain demographic groups have lower adaptive capacity to respond to these barriers due to lower levels of time, energy, money, and sociopolitical standing. The susceptibility of certain demographic groups toward differentiated housing recovery outcomes has been documented across multiple groups including women, the elderly, lower-income households, households with unemployed adults, and homeowners with lower levels of education (Ardalan et al. 2010; Baker and Cormier 2015; Brouwer et al. 2007; Enarson et al. 2006; Enarson and Morrow 1998; Gotham 2014; Ingram et al. 2006). After Hurricane Andrew, minority households on average suffered more extensive damage and had more difficulties throughout the reconstruction process (Zhang and Peacock 2009). Vulnerabilities can also manifest in dynamic ways during discriminating recovery processes in the form of exclusion or lack of representation and voice in recovery decisions. For example, during the reconstruction of public housing in Galveston after Hurricane Ike, residents—predominantly lower-income households, racial minorities, and individuals with disabilities—had a limited voice in important recovery decisions (Hamideh and Rongerude 2018). The proposed hypothesis in this study that compounding socioeconomic vulnerabilities are likely associated with higher levels of informal housing is designed to capture the difficulties seen in the housing reconstruction process in Puerto Rico. To truthfully understand vulnerabilities, one needs to understand sensitivities within individual cultural and institutional contexts. Barriers to reconstruction in Puerto Rico specifically such as high costs for construction, difficulties obtaining permits without extra money or connections, and the time and energy that is required to go through the permitting and reconstruction process suggest that demographics with lower levels of time, energy, money, and sociopolitical standing may have a more difficult time reconstructing according to formal standard. While this is true for the case of Puerto Rico, it has evidential backing in other disaster recovery scenarios, where overall, women, the elderly, lower-income households, households with unemployed adults, and homeowners with lower levels of education have more difficulty in their housing recovery process due to limited access to resources (Ardalan et al. 2010; Baker and Cormier 2015; Brouwer et al. 2007; Enarson et al. 2006; Enarson & Morrow 1998; Gotham 2014; Ingram et al. 2006).

Research has also shown that socioeconomic vulnerabilities are compounding, meaning they have a stronger effect when they exist together (Curtis et al. 2007; Morrow 1999). The vulnerability of minority ethnic groups (e.g., Latinx or Black communities) to disasters is compounded for women that belong to the minority ethnic groups, leading to marginalization during recovery decisions and limiting access to resources (Morrow 1999). Studies in New Orleans after Hurricane Katrina found that racial minorities are also compounded by poverty (Curtis et al. 2007). During the 2020 Covid-19 pandemic, researchers found a ‘triple burden’ on women that was compounded by the effects of global quarantine and widespread disease (McLaren et al. 2020).

Certain vulnerabilities can pertain not only to demographics and personal attributes but also to housing type. For example, informal housing residents potentially carry a

pre-existent level of vulnerability due to the stigmatization and disempowerment of informal housing residents (Romero-Lankao et al. 2014). This is particularly true in post-2017 Puerto Rico where multiple recovery stakeholder groups and other powerful interests including state and federal government leaders have identified reducing numbers of informal housing as a key priority in the recovery process (Government of Puerto Rico, Department of Housing 2018; Resilient Puerto Rico Advisory Commission 2018). However, this is complicated by the fact that before 2017 over half of the houses in Puerto Rico could be categorized as informal (Viglucchi 2018), and that historical housing policy in Puerto Rico previously promoted and supported self-help building practices (Fuller Marvel 2008).

This study extends the disaster literature to understand compounding vulnerabilities in the context of informal housing reconstruction, which is ‘officially’ discouraged by some stakeholders but locally supported and perpetuated. While a majority of housing for low-income communities is supplied by the informal sector (Johnson and Lizarralde 2012), current research on socioeconomic vulnerability tends to focus on demographics and household characteristics, with limited attention to the inherent vulnerability present in informal housing situations. While age, gender, education, and economic status play a critical role in how households recover, they are not fully comprehensive of vulnerability in regard to housing. Informal housing, especially the way that it exists in the Puerto Rico context, is not necessarily subpar construction or unpermitted work, but a historically prevalent means of taking control over one’s own situation. However, in the context of Hurricanes Irma and Maria, it is important to acknowledge that this type of construction has increased vulnerability to procedural disempowerment because it does not fit within the formal recovery structure set in place by the official recovery plans.

Housing vulnerability also depends on a set of local laws related to housing construction, ownership, and insurance which can diminish the ability of households to rebuild. These laws differ across states and countries, but informal housing leads to increased housing vulnerability in almost every context. For example, residents of informally acquired housing in urban centers in Buenos Aires, Argentina, face imminent eviction due to the inability to secure land tenure (Muñoz 2018). In the US context, residents in informal communities along the Texas-Mexico border suffer from a lack of community infrastructure and access to social programs due to their informal status (Ward 2014). Alternative housing types in the USA, such as public housing, mobile homes, and informal housing, often face higher levels of housing vulnerability, for example mobile home parks generally house more concentrated socioeconomically vulnerable populations, experience higher physical vulnerability to disaster, face stigma from government officials and programs, and often are at a disadvantage in the enforcement of disaster policy (Rumbach et al. 2020). These effects parallel what is often seen in the literature regarding informal housing, positioned in this study as another type of ‘alternative’ housing with more challenging recovery trajectories.

Understanding the connections between vulnerability and informal housing is important for describing who is likely to live in informal housing. While informal housing reconstruction provides some benefits to households who have been unable to engage in formal housing reconstruction, and is often their only way of maintaining progress in recovery, it brings significant risk. Therefore, understanding how to support informal housing residents by examining their overlapping vulnerabilities in regard to socioeconomic vulnerability, can enhance the capacity of recovery programs and NGOs to better support these households in recovery, for example, through providing access to technical assistance for learning safe reconstruction techniques or connecting them to additional financial resources for reconstruction.

5 The Case of Puerto Rico

Puerto Rico is a unique case in the context of housing informality, post-disaster reconstruction, and socioeconomic vulnerability, due to the complex relationship with the mainland USA and historically high prevalence of informal housing throughout the Archipelago.

In Puerto Rico, local vulnerabilities related to housing primarily include homeownership as a historical practice where citizens informally passed on land and homes through generations, with unpermitted construction often encouraged and supported by local politicians (Fuller Marvel 2008). While in Puerto Rico occupancy is equal to right to place (Fuller Marvel 2008), this right has not been acknowledged or accepted by recovery agencies and the federal government as proof of ownership and right to place (Viglucchi 2018). As a result, many households are denied assistance, amplifying their level of vulnerability. This discrepancy affects a large segment of society as over half of structures are considered informal in Puerto Rico (Viglucchi 2018). Ignoring these local housing vulnerabilities in addition to the other socioeconomic vulnerabilities (e.g., gender, age, and poverty) may limit our understanding of where communities may struggle the most and ability to provide the proper response. Particularly, it is important to understand how housing informality as a vulnerability factor not only affects recovery outcomes, but also exacerbates the effect of other socioeconomic vulnerabilities on recovery. Puerto Rico has been both a colony of Spain and the USA, and much of the original Spanish housing policy permeates though housing policy in Puerto Rico to this day. Informal housing has a long history in Puerto Rico; in fact, it was the first place in the world to write ‘aided self-help’ housing into their housing policy in the early twentieth century (Harris 1998). This tradition of aided self-help housing has continued through history until today where many houses in Puerto Rico have been built by homeowners and their networks, without the documentation generally required by US housing policy. This has led to mismatches in the expectations compared to the reality of housing construction, situating Puerto Rico in an unfortunate intersection between historically accepted informal practices, and post-disaster standardized housing assistance policies that do not contain sufficient flexibility to consider the unique Puerto Rican housing experience. This specific mismatch makes the complex reality of informal housing in Puerto Rico unique from informal housing throughout the rest of the world and requires researchers to view the relationship between informal housing and vulnerability in nuanced detail.

Besides the context of informal housing, to place this study geographically, culturally, and historically in Puerto Rico, it is important to understand the specific vulnerabilities that are often encountered on the Archipelago. These include high percentages of elderly and/or disabled residents, high rates of poverty, and physical vulnerability as well as significant governance differences with the US federal or state governments.

First, the Archipelago of Puerto Rico has seen a long-term exodus of young and able-bodied residents to the mainland USA due to the significant economic challenges and lack of opportunities, which has only intensified in the two years since Hurricane Maria. This has left Puerto Rico with a proportionately older, disabled, terminally ill, and non-working population (Hinojosa and Meléndez 2018). The status of Puerto Rico as a territory of the USA has had a long-term effect on the policies governing the Archipelago, as well as relationship with the federal government. There is a general disenchantment with the US colonial policy (Cortés 2018) that has manifested in a general distrust of US intentions on the Island. This can often create a feeling of ‘otherness’ between the residents of Puerto Rico and the federal government tasked with the recovery process after Hurricanes Irma

and Maria. Historically, since 1917 when the Island residents were granted US citizenship there has been a series of economic policies that have kept the residents burdened with unpredictable economic activity and reducing their ability to be economically independent and thriving (Cortés 2018).

The Archipelago is plagued with high rates of poverty; at the time of Hurricane Maria and today, the poverty rate was above 50% (US Census Bureau 2019). The median and mean annual income in Puerto Rico is \$19,775 and \$31,672, respectively, compared to \$57,652 and \$81,283 in the entire USA (US Census Bureau 2019). Previous to the hurricanes, in 2016 a Fiscal Control Board was enacted over Puerto Rico with full jurisdiction over the Archipelago's budget. This has resulted in increased tensions over spending decisions and delegation of authority. In addition to the already tense and complex financial situation, this is the first time in the history a country is going through a disaster recovery process as the same time as a major financial crisis. These structural economic and political challenges intersecting with the impacts of the Hurricanes trickle down to the most vulnerable populations by straining access to resources and decreasing the enforcement and oversight of official regulations.

The vulnerable populations of Puerto Rico also live disproportionately in the steep, mountainous regions which are prone to landslides and isolation in disaster events, as well as flood zones along the coast. These areas are agricultural zones and rural, and hence disproportionately populated by vulnerable communities such as low-income, rural, and Indigenous communities.

6 Methodology

6.1 Research Context

The research team administered surveys 15 months after Hurricane Maria, from December 2018 to January 2019. Surveys were administered in two municipalities, Loíza and Yabucoa. These two areas were chosen given the significant damage to the housing stock from the hurricanes, and diverse geographic and vulnerability factors, as discussed below.

Loíza is situated in the northeastern side of Puerto Rico; it borders the main airport and is in close proximity to the capital city and Puerto Rico's main metropolitan area of San Juan. The municipality is small but densely populated, with a population of 26,000 people and unemployment rate of 7.9%. Although Loíza was not in the direct path of Hurricane Maria, the housing stock in the municipality was significantly affected and required major reconstruction. The municipality topography is flat and coastal and thus is vulnerable to extensive flooding and wave impacts from the ocean during hurricane events. In terms of financial resources, the average annual income is \$17,273, below the national average of \$19,775, and significantly below the US average of \$57,652 (US Census Bureau 2017). Additionally, 51.9% of the Loíza population live below the poverty line (US Census Bureau 2017).

Yabucoa is situated in the southeastern corner of Puerto Rico and was the first area hit by Hurricane Maria. It is a more isolated area than Loíza with considerable distance from major metropolitan areas, increasing the risk of isolation from resources after a disaster. Yabucoa has a population of 33,629, and the unemployment rate is at 12.2%. Topography includes flat and coastal and mountainous regions, both of which are vulnerable to the impacts of a hurricane. Main physical risks include flooding, wave impacts, and landslides

in the mountains. In terms of financial resources, the average annual income in the area is \$15,586, slightly less than that of Loíza, and half of the population live below the poverty line (U.S. Census Bureau 2017).

These two sites were selected as the areas of study due to the high volumes of housing damage, historically perpetuated socioeconomic vulnerability in the areas, and high rates of informal housing. Yabucoa is often referred to as ‘ground zero’ for Hurricane Maria, as it is the area of first landfall and was located directly in the path of the eye of the storm (Jervis 2018). As such, Yabucoa experienced the most powerful forces from the Hurricane before it weakened as it progressed across the Archipelago, evident in the severe housing damages left behind throughout the municipality. At the same time, Yabucoa has a significant portion of their more vulnerable populations living along the coastline in well-established fishing communities, and up in the mountainous areas—both of which have posed significant vulnerability to damage from hurricanes (Prevatt et al. 2018).

Regarding the second site, Loíza creates a unique juxtaposition as it sits just miles from the main metropolitan area of San Juan and, however, has a starkly different reality when it comes to access to resources and the speed of recovery post-Hurricane. Loíza has historically had a dense Afro-Caribbean population with significant documented struggles with establishing right to space, and their sociopolitical standing within Puerto Rico (Fusté 2010). The area has also been experiencing significant coastal erosion, endangering houses along the coast and further inland with a greater degree of protection from the sea during storm events. While there are high volumes of damage, vulnerability, and informal housing throughout the Archipelago and similar areas have had comparable issues with recovery, the two sites of Yabucoa and Loíza were eventually selected for their manifestation of intersecting issues that have exacerbated recovery issues post-Hurricane Maria. These two sites enabled the researchers to observe and better highlight the challenges of recovery within a context of high socioeconomic vulnerabilities and informal housing.

6.2 Data Collection

Surveys were distributed to 305 households in person, door-to-door, between December 2018 and January 2019. Each survey was completed in an average of 15–30 min and included 43 questions. First, the survey included demographic data, including gender, age, education, annual income, employment status, and number of adults and minors living in the home. Second, the survey asked for indicators of housing informality pre-hurricanes, such as having ownership documents. Third, the survey provided a definition of informal housing reconstruction and asked on a scale of 0–100, and the percentage of the reconstruction they have completed could be categorized as informal. This study was reviewed by the Iowa State University Institutional Review Board (IRB) to ensure ethical research with human subjects. This study is included as a modification of study number 18–111-00 and deemed exempt from full review.

Surveys were written in English and reviewed by translated to Spanish by a native Puerto Rican Spanish speaker. Surveys were administered in Spanish, and most were administered verbally with a few exceptions when the surveys were left at homes with the consent of a resident and collected later in the day. Seven paid survey administrator from local universities in Puerto Rico was hired to assist with survey distribution. The administrators participated in a training about the overall goals of the project, goals of each survey question, and institutional review board (IRB) requirements. After the training, they observed the administration of one survey in the field, were observed as they did one practice survey, and then

participated in a debrief session to address any questions and provide feedback before they started conducting surveys on their own.

The survey-sampling procedure followed a quota-sampling method (Moser 1952; Nahayo et al. 2017). This method typically includes gathering surveys from a predetermined quota of specified groups of people following previous theory, such as gathering half male and female respondents. This method seeks to ensure that the sampled population is representative of the entire population to improve generalizability to the larger population of Puerto Rico. In this study, these sampling methods took the following form. The municipalities of Loíza and Yabucoa are officially split into six and 12 neighborhoods ('barrios'), respectively. We approached and prioritized neighborhoods according to the proportion of the total population of the municipality that lives in each neighborhood to capture relatively proportional trends in existence. For example, 8% of the population of Loíza lives in the neighborhood of Torrecilla Baja. Hence, we attempted to maintain 8% of our surveys from that neighborhood. Within those quotas, convenience sampling was used to choose participants, that is, choosing participants that are most convenient to access (Norris 2006). Due to a lack of reliable online or telephone communication capabilities in the two communities, the sampling plan necessitated convenience sampling, taking the form of door-to-door communication. The survey did not include those who were not home, did not answer the door, or did not wish to participate. Prior to administering the survey, we verified the following three screening qualifiers: (1) Did the respondent own the house? (not an indication of being in possession of ownership documents, instead indicating that they were not renting the house from another owner) (2) Was the respondent the head of the household? (3) Did their house suffer significant damage so as to need reconstruction that would warrant a permit or contractor? If they answered yes to those three qualifiers and were willing to participate, we then administered the survey. In total, 305 households were surveyed: 163 from Loíza and 142 from Yabucoa.

It is important to note that for the purpose of this study, only owners were included in the analysis, and all renters, including those who undertook improvements to the house, were excluded. Typically, while renters qualified for financial assistance to replace personal belongings (Garcia 2021), financial assistance specifically for reconstruction was intended only for owners and not renters, to discourage duplication of assistance issues that had been encountered in recovery from previous disasters. This was true even if the renters were undergoing reconstruction and added extra bureaucratic implications outside of the scope of the study. Further, the vulnerability characteristics of owners are distinct from renters especially in a post-disaster context, including issues of permanence, social networks, and economic and demographic characteristics (Lee and Van Zandt 2019). While both groups are important to study, their unique positions in the recovery after Hurricane Maria would require the groups to be studied separately for the intended goals of this study.

6.3 Data Analysis

Data analysis includes descriptive statistics to determine sample demographics and patterns of housing reconstruction, and cross-tabulations between variables. Additionally, a series of regression analyses with interaction effects were conducted to capture the compounded effects of vulnerability characteristics on informal reconstruction. Significance is noted for two-tailed $p < 0.1$, $p < 0.05$, and $p < 0.01$. The variables used for operationalizing socioeconomic vulnerability include: age, gender, level of education, annual income, employment status, and ownership documents.

Regression analysis includes logistic regression using control variables, and a combination of continuous and binary socioeconomic vulnerability variables, including their main effects and interaction effects between the variables. The dependent variable is informal housing reconstruction, included as a binary variable coded as 0 if the respondent indicated no use of informal housing reconstruction, and 1 if the respondent had indicated any use of informal housing reconstruction. The survey collected 46 instances of respondents with no use of informal housing reconstruction, constituting 17% of the sample, and 224 instances of respondents that use informal housing reconstruction, constituting 83% of the sample.

Control variables include the level of housing damage, measured on a scale from 0 to 18, with six different components of the house measured on a four-point scale (from 0 to 3) for their level of damage caused by the hurricanes. Level of damage was indicated by the respondent, not by the survey administrator. The second control variable is a continuous measure of how many minors live in the home.

Independent variables include socioeconomic vulnerability indicators. All independent variables include binary responses of 0 and 1 with dummy variables created for the models, save for annual income which is measured on a continuous scale, binned in intervals of \$5,000. In terms of coding for statistical modeling, gender is coded as 0 for male and 1 for female. Age is coded as 0 for below 65 for 1 for 65 and above. Education is coded as 0 if the respondent had not completed high school, and 1 if the respondent had at least completed high school. Employment status is coded as 0 if there are no employed adults in the home, and 1 if there is at least one employed adult in the home. Ownership is coded as 0 if they have ownership documents and 1 if they do not.

6.4 Limitations

Limitations of the present study include sampling in only two municipalities; while they are representative of rural communities in Puerto Rico, robustness of the study will be improved by adding more communities and increasing survey numbers in each community. The administration of the survey occurred one year after Hurricane Maria, therefore giving enough time for reconstruction trends to become apparent. However, this timing creates the risk of recall bias, which may affect the responses on events that happened closer to the time of the Hurricane. This could be improved by implementing a time series approach that surveys participants at multiple intervals to better understand the changes and patterns in household reconstruction and attitudes. Further, survey administration primarily occurred during daylight hours through face-to-face interaction. While this is standard practice, it is important to note that it may contribute to a dataset that is missing households who did not wish to answer the door or who were not home at the time. Specifically, this may have led to capturing a sample population that is more likely to be at home during the middle of a weekday, such as older or unemployed individuals. Additionally, the door-to-door method that was used to administer the survey was similar to some of the aid-providing agencies and FEMA inspectors, and survey administrators noted that a number of respondents mistakenly identified the researchers as employees of those organizations. This may have affected how respondents answered certain questions, specifically those insinuating undesirable or unpermitted behavior. Respondents may have been more likely to answer the questions in a way that sounded positive to those organizations, such as underreporting informal behavior or lack of ownership documents. The authors attempted to mitigate dishonest responses by describing the anonymity of the study and how there are no right or wrong answers to these questions. The authors communicated that nothing the respondents

discuss will be shared or documented with identifiers, and that the study is being conducted for research purposes and the survey will in no way affect their qualification for reconstruction assistance. The authors were also careful to avoid any negative verbiage in survey questions about informality, such as ‘illegal’ or ‘unsafe.’

It is also important to note that high mortality rates after past disasters have often been associated with socioeconomic vulnerability characteristics (Wisner et al. 2004). Therefore, due to the timing of this survey over one year since the disaster event, it is possible that the very most vulnerable were not in fact captured in the survey, thus limiting this study’s conclusions regarding the most vulnerable and households with more intersecting vulnerabilities. Further studies should be conducted that captures more diverse vulnerability variables as they particularly relate to post-disaster housing reconstruction, such as disability status, or language barriers between households and reconstruction stakeholders or gatekeepers of resources.

7 Results

7.1 Description of Informal Housing Reconstruction and Socioeconomic Vulnerability Indicators

Overall, 33% of the sample used only informal housing reconstruction, and 83% of respondents used some form of informal housing reconstruction in combination with formal practices. These results indicate that only 17% of respondents rebuilt every section of their home following a completely formal process. These percentages indicate that many respondents have decided to engage in informal housing reconstruction, even if not for the entirety of the home. This shows easier access to resources for informal housing reconstruction, even among the most vulnerable, compared to formal processes. Such comparison could be due to impossible access to other resources, leaving few options but utilizing informal resources and processes. RAND Corporation studies have indicated the formal sources of assistance such as government programs and insurance payments have provided significantly low dollar amounts of housing reconstruction assistance compared to the assessed damage and need, roughly \$30 billion in deficit (Clancy et al. 2020). Given this gap in assistance, the alternative to informal housing for many respondents was homelessness or overcrowding with extended family homes.

Table 1 presents sample demographics compared with the average in Puerto Rico according to the US census. The sample includes 65% female respondents, with a mean age of 61 years, median age of 62, and a range from 18 to 98 years. The sample shows a very old average age, especially compared to the mean age in Puerto Rico. This discrepancy could be a symptom of the long-term outmigration to the mainland USA, with those joining the Puerto Rican diaspora in the USA being proportionally younger and with children (Hinojosa et al. 2019; Mora et al. 2018). Educational attainment is low; more than one-third of the sample does not have a high school diploma, and only 23% have a bachelor’s degree or higher. The sampled communities are also in significantly high poverty and show high levels of unemployment. In terms of income, 30% of the sample have no form of reportable income, 61% have an income of \$10,000 or less annually, and only 1% of respondents earn more than \$40,000 annually. Unemployment rates are high among the surveyed households; 59% are unemployed. This could also be a symptom of families leaving in search of increased opportunity, potentially leaving behind a population that is on

Table 1 Sample demographic descriptive statistics

Demographic	Study sample	Loíza	Yabucoa	Puerto Rico
Gender	65% female	53.6% female	51.7% female	52.5% female
Age	Median age = 62	Median age = 40.3	Median age = 42.9	Median age = 43.1
Education	33% do not have a high school diploma	25% do not have a high school diploma, 14.7% have a bachelor's degree or higher	29% do not have a high school diploma, 18% have a bachelor's degree or higher	23.5% do not have a high school diploma
Annual income	23% have a bachelor's degree or higher			25.9% have a bachelor's degree or higher
	30% have no form of reportable income	Median household income = \$17,852, people in poverty = 48.2%	Median household income = \$16,295, people in poverty = 53.1%	Median household income = \$20,539, people in poverty = 43.5%
Employment status	61% have an income of \$10,000 or less annually			
	59% have no employed adults in the home	Employment rate = 49%	Employment rate = 38.6%	Employment rate = 44.4%
	41% have one or more employed adults			
Ownership documents	74% have documents	Data not available	Data not available	Roughly 50% of housing is categorized as informal, much of which is due to lack of ownership documents (Vigluecci 2018) ^a
	26% do not have documents			
Number of minors in the home	58% of households have no minors	48.1% of households have at least one minor	41.8% of households have at least one	38.6% of households have at least one minor
	12% have 1			
	2% have more than 3			

^aThere are limited data regarding specific numbers of informal housing; thus, this data point is a rough estimate.

Table 2 Cross-tabulations—age and gender

Age	Gender		Total
	Male	Female	
Below 65	15%	43%	58%
65 and above	17%	25%	42%
Total	32%	68%	100%

Pearson Chi-squared value = 7.3062

 $p = 0.007$ **Table 3** Cross-tabulations—age and employment

Age	Employment		Total
	No employed family members	At least one employed family member	
Under 65	28%	29%	57%
65 or above	34%	9%	43%
Total	62%	38%	100%

Pearson Chi-squared value = 23.7553

 $p = 0.000$

average older and in higher poverty. The discrepancy between the 30% of households having no form of reportable income and 59% of households reporting no employed adults in the home, which should be roughly equal, could derive from the informal sector. Many households, especially in the surveyed households, engage in an informal economy centering around construction labor, fishing, and selling food out of their homes. The informal economy encompasses work that is not regulated or protected by the state and can include such work as selling food out of the home, or cash payments under the table at a formal job where the individual does not exist on payroll (Portes and Haller 2010). While these activities bring in money, the respondent may still consider themselves ‘technically’ unemployed when responding to the survey.¹

Column 2 data were obtained from the study survey, and columns 3–5 include US census data for the sampled municipalities and Puerto Rico average (US Census Bureau).

7.2 Compounded Socioeconomic Vulnerability Indicators

Tables 2, 3, and 4 present cross-tabulations of the independent variables with statistically significant relationships at $p < 0.1$, two-tailed. Independent variables include gender, education, employment status, and ownership documents. Table 2 presents cross-tabulations of gender and age and suggests that female respondents in our sample are also younger on average. It is important to note here that given the sampling method, this result may be a commentary on social structure and gendered duties

¹ Note: the authors noted that confusion among participants regarding social security benefits as income during survey administration may have also added to this difference.

Table 4 Cross-tabulations—education and employment

Education	Employment		Total
	No	Yes	
Did not complete high school	23%	12%	35%
Completed high school	36%	29%	65%
Total	59%	41%	100%

Pearson Chi-squared value = 2.9154.

$p = 0.088$

Table 5 Odds ratios logistic regression

Use of Informal Reconstruction	Model 1	Model 2	Model 3
<i>Controls</i>			
Level of Damage	1.048	1.095	1.112*
Children in the home	0.956	1.798	2.537
<i>Independent Variables</i>			
Gender		1.242	1.251
Education		0.231***	0.179***
Income (continuous)		0.941	0.863
Employment		0.519	2.969
Ownership		1.678	9.717***
<i>Variable Interactions</i>			
Employment X Ownership			0.052***
Constant	2.943*	2.684	0.901
R ²	0.0060	0.1073	0.1665
Prob < chi ²	0.6453	0.0511	0.0054

* = $p < 0.1$, ** = $p < 0.05$, *** = $p < 0.01$

because results show that younger men were more likely to not be in the house during the day on weekdays. Table 3 presents cross-tabulations of age and employment status and suggests that older respondents are much more likely to experience unemployment than younger respondents. However, also note that for younger respondents, it is equally likely to be unemployed than it is to be employed. Table 4 presents cross-tabulations of education and employment and suggests that respondents who did not complete high school are more likely to be unemployed. It is important to note in this table the poor rates of unemployment, regardless of education.

These tables show that ownership does not co-occur with any other variables and/or show any significant cross-tabulations. This suggests that ownership does not co-occur with one vulnerability group more significantly than others. Therefore, this study rejects previously identified trends in literature, suggesting that housing informality is more common among households with higher socioeconomic vulnerability. Instead, results suggest there are multiple factors beyond socioeconomic vulnerability that coincide with a household's ability or decision to procure land tenure, such as historical development of housing policy in Puerto Rico, or lack of enforcement in housing regulation (Fuller Marvel 2008).

7.3 Socioeconomic Vulnerability and Informal Housing Reconstruction

Table 5 presents results from three logistic regression models, testing the compounding nature of vulnerability for use of informal housing reconstruction. The original model included all variables identified in the literature, and backward stepwise hierarchical regression was used to determine the model with the best-fit R^2 and χ^2 value. The best-fit model includes level of damage and number of minors in the household as control variables. Independent variables in the best-fit model include gender, education, annual income, employment status, and ownership. Age was the only independent variable excluded from the model based on model fit. The base level for all variables in the analysis is 0.

Model 1 includes only control variables to understand the effect of these variables as a baseline condition before their effect is removed for the next models. Results suggest there are no significant predictors of informal housing reconstruction among our control variables, and the Chi-squared value suggests a poor fit model and suggests the need for inclusion of additional variables. Model 2 includes control variables and all vulnerability indicators as individual effects. Results from model 2 suggest that in the absence of interactions, the education level of the respondent is the only significant predictor of informal housing reconstruction (*odds ratio* = 0.231, $p = 0.006$). This suggests that respondents who have completed high school have 77% lower odds of using informal housing reconstruction after controlling for the other vulnerability variables.

Models including all possible two-way interactions were tested one by one, and only one interaction showed significant results, presented in model 3. Model 3 suggests ownership and employment are compounding variables (*odds ratio* = 0.052, $p = 0.008$), that is, respondents who are unemployed and have ownership documents have 95% lower odds of using informal housing reconstruction, compared to unemployed respondents without ownership documents, employed respondents with or without ownership documents. After including the employment and ownership interaction, education maintains a similar effect as model 3 (*odds ratio* = 0.179, $p = 0.003$), that is, respondents who have completed high school have 82% lower odds of using informal housing reconstruction. Level of housing damage also has a significant effect (*odds ratio* = 1.112, $p = 0.097$), suggesting that respondents who experienced higher levels of damage have 11% higher odds of using informal housing reconstruction. Ownership too has a significant individual effect (*odds ratio* = 9.717, $p = 0.007$), suggesting that respondents without ownership documents have 872% higher odds of using informal housing reconstruction or nine times as likely.

The interaction plot in Fig. 1 visualizes the significant interaction identified in Table 6. Lines that intersect or trend toward intersection suggest the presence of interaction. The intersecting trend lines presented in this figure suggest the presence of an interaction between employment and ownership, such that respondents who have ownership documents have higher odds of using informal reconstruction if they are also employed, but if they do not have ownership documents, they have a higher odds of using informal reconstruction if they are unemployed.

Post hoc Bonferroni adjustments were then conducted to adjust the comparison of means for multiple tests and further investigate the group differences, presented in Table 6. Bonferroni adjustment is a method commonly used during pairwise comparisons to account for the possibility of one of incorrectly rejecting a null hypothesis. When multiple comparisons are made, the chances of observing a statistically

Fig. 1 Interaction plot

Table 6 Comparison of use of informal reconstruction by employment and ownership group (Bonferroni adjustment)

Interaction groups	Contrast	Standard error	Bonferroni z-statistic	Bonferroni p-value
Unemployed without documents vs Unemployed with documents	0.687	0.706	0.97	1.000
Employed with documents vs Unemployed with documents	1.873	0.727	2.58	0.060
Employed without documents vs Unemployed with documents	−0.401	0.715	−0.56	1.000
Employed with documents vs Unemployed without documents	1.186	0.813	1.46	0.870
Employed without documents vs Unemployed without documents	−1.088	0.824	−1.32	1.000
Employed without documents vs Employed with documents	−2.274	0.838	−2.71	0.040

significant result by chance increase, thus using Bonferroni adjustments accounts for this increase in the chance of rejecting a null hypothesis in error. In this case, this is done by multiplying the resultant p-value by the number of tests conducted, capped at a value of 1.0. These adjusted p-values are presented in Table 6.

The Bonferroni post hoc adjustment and pairwise comparisons suggest that there are two group comparisons with statistically significant differences in means. The first difference exists for respondents with ownership documents, between those who were and were not employed ($p=0.060$), and for respondents who did report being employed, those with and without ownership documents ($p=0.040$). This suggests that respondents with ownership documents have higher odds of using informal reconstruction if they are employed, and similarly that households who report that at least one household member is employed, have a higher odds of using informal reconstruction if they also report that they have

ownership documents. Overall, these results indicate that the group of respondents that had the highest odds of using informal reconstruction were those with ownership documents and at least one employed adult.

8 Discussion

8.1 Socioeconomic Vulnerability Cross-Tabulations

The widespread use of informal housing construction among respondents suggests that informal methods are accessible and not widely regulated or penalized. Many respondents were surprised at the definition of informal housing given during the survey, expressing that these practices are ‘the normal way construction is done here.’ This overwhelming use of informal reconstruction aligns with the current literature that suggests vulnerable communities frequently encounter difficulties in the reconstruction process and thus seek out alternatives to traditional paths of housing reconstruction (Wisner et al. 2004).

The first analysis included cross-tabulations between the measured socioeconomic vulnerability variables, including gender, age, education, annual income, employment status, and ownership, to understand if any socioeconomic vulnerability variables had a significant correlations, resulting in compounding socioeconomic vulnerabilities. The cross-tabulations show that there are only a handful of socioeconomic vulnerability variables that show a significant correlation. Cross-tabulations show that older respondents on average have lower rates of education. This could be a result of the long-term exodus from Puerto Rico, specifically of young, educated individuals. This exodus has left behind an older generation who are on average lower educated, terminally ill, and disabled (Hinojosa et al. 2019). This result may also potentially be a reflection of the sampling techniques and resultant sampled population. Surveys were gathered from homeowners who were at home during the day and willing to participate, therefore collecting a larger sample of the older population and/or without unemployed, a potential limitation of the study. Further, cross-tabulations show that respondents with lower levels of education also tend to earn lower levels of income. This aligns with census findings that show that those with higher education on average earn higher incomes and experience lower levels of unemployment (U.S. Bureau of Labor Statistics 2020). A final cross-tabulation shows that older respondents are also more likely to have no employed adults in the home. This suggests that older respondents are more likely to live alone, or only with other older or unemployed individuals.

It may appear surprising that the ownership variable does not have any significant tabulations with other socioeconomic vulnerability variables. Trends in existing literature which suggests that lower-income or education levels hinder securing legal housing status (Way 2009). However, lack of ownership documents is a historical issue which has been normalized and often encouraged throughout the development of Puerto Rico. Informal housing is the normal and not an ‘alternative’ practice. It has been widely practiced across multiple vulnerable and non-vulnerable groups (Fuller Marvel 2008; Viglucci 2018).

The next analysis included a series of logistic regression models to evaluate potential relationships between socioeconomic vulnerability variables and informal housing reconstruction. Results from model 2 show that education level is the only significant predictor of informal reconstruction. This suggests that when controlling for level of damage, number of minors in the home, and socioeconomic vulnerability variables, a household with lower levels of education is more likely engage in informal housing reconstruction.

This confirms trends found in previous studies regarding socioeconomic vulnerability. Households with lower levels of education are less likely than higher educated homeowners to buy or rent a new home after a disaster event (Frankenberg et al. 2013). This echoes previous research that suggests households with lower levels of education can have more difficulties engaging in formal and legal processes, particularly when they require extensive paperwork and attendance in official meetings (Way 2009). In this context, this could include obtaining and filling out applications for FEMA assistance through their Individual and Households Program (IHP), understanding and engaging with the appeal process, or going through the process of proving ownership without ownership documents as was the issue experienced by a large percentage of Puerto Rican households.

Results from model 3 provide interesting insights regarding compounding socioeconomic vulnerabilities in the context of informal reconstruction. The interaction between ownership and employment variables presented in model 3, and the subsequent pairwise comparisons with Bonferroni post hoc adjustments, suggest that households with employed members and ownership documents are the most likely to engage in informal reconstruction, compared to households without employment or ownership documents, households with employment and without ownership documents, and households with employment and without ownership documents. In Puerto Rico, a majority of households did not qualify for financial assistance from FEMA's IHP program, primarily due to the absence of ownership documents (Doberstein and Stager 2013; Viglucci 2018). As such, it is expected that those with ownership documents would be less likely to engage with informal reconstruction. However, considering that 82% of the study sample engaged in informal reconstruction, and 74% of the sample reported having ownership documents, it is clear that informality was widespread throughout the sample. This insinuates there are other drivers of informality in addition to ownership. The survey was conducted 15 months after Hurricane Maria, and it was already evident that local and international organizations and churches had stepped in to provide reconstruction services for people who found themselves disqualified from FEMA assistance or otherwise unable to reconstruct on their own. FEMA IHP applications initially required ownership documents and denied assistance to those who could not prove ownership (Viglucci 2018). As such, households with ownership documents were able to engage with the FEMA process, while those without ownership documents were not. Additionally, many noted that households working with FEMA services experienced significantly slow timelines (Allen and Penalzoa 2019) or poor work that had to be fixed by the household members later on (Mendez Gonzalez and Wiscovitch 2019). As a result, homeowners who received FEMA assistance likely felt the desire to self-perform and engage in informal reconstruction, while the rest of the households which were denied FEMA IHP assistance were more likely to use the assistance from non-governmental organizations. These alternative organizations, such as Taller Salud, Housing counseling services, the Ricky Martin Foundation, All Hands and Hearts, ADRA Puerto Rico, SBP Americorps, and other similar organizations, often hired or used volunteer contractors, so respondents to the survey usually marked them as formal reconstruction. Many of these organizations have mentioned targeting and prioritizing communities where they knew there were large numbers of informal homes or vulnerable households. FEMA also often referred homeowners without ownership documents to these organizations because they knew these organizations could be more helpful given their flexibility; therefore, respondents without ownership documents may have been among the first cases brought to the organizations providing formal reconstruction services outside of the FEMA process. One of the important policy implications of this finding is the necessity of strategizing with local organizations that can fill in gaps left behind by formal housing assistance policy,

thus promoting safety nets for households unable to meet formal government assistance eligibility requirements. A streamlined and well-connected assistance network from the onset of disaster recovery planning can ensure that all subgroups of residents are considered and supported throughout the duration of post-disaster housing reconstruction. In the end, local, on-the-ground organizations understand the unique needs and priorities of the populations they work with on a daily basis and can promote place-based recovery strategies that consider contextual needs.

Further, homeowners in Puerto Rico have noted that even if they received financial assistance from FEMA, it was often insufficient and they end up self-performing the rest of the work (Brown 2018). FEMA provided lump sum amounts from estimates of required costs to bring the house back ‘safe habitation,’ that is, to a habitable and safe state. This safe habitation state is often only a few rooms and a bathroom, and not all of the reconstruction needed on the house. Therefore, to complete all reconstruction needed, many homeowners were required to self-perform the rest of the work. Alternatively, the non-governmental organizations who have stepped in to provide reconstruction, have a working policy of completing all reconstruction that is needed on the home, above and beyond the point of ‘safe habitation,’ therefore reducing the need to self-perform and engage in informal reconstruction.

On the other hand, the results from the ownership and employment interaction in model 3 also suggest that for respondents with ownership documents, the odds of using informal reconstruction increases if there is also at least one employed adult in the household. This trend suggests that employment provides vital access to resources to support informal reconstruction. While this could come in the form of financial resources earned from employment, it is important to note that the model did not suggest that any changes in annual income had an effect on the household’s use of informal reconstruction. Therefore, we cannot suggest that the increased financial resources earned from employment were the driver for engagement with informal reconstruction and instead suggest an alternate hypothesis that this trend may be more due to the social networks created through employment. Specifically, employment is potentially important for creating strong networks that can be activated in time of need to assist with reconstruction. Places of employment often connect people who would otherwise not interact, and depending on the place of employment, can assist in the reconstruction processes. During fieldwork in Puerto Rico, many respondents noted the role of their employers and coworkers as a significant source of support during initial response and recovery. This support could be in the form of wider and stronger networks including people who are skilled in or knowledgeable about reconstruction, as well as the strength of relationships that have been built through employment that could make employment associates want to help each other. Strong social relationships that provide mutual benefit create social capital that has been shown to be a key source of support in times of disaster recovery (Aldrich 2012; Portes 2000; Putnam 2000; Talbot et al. 2020). In addition, strong social connections to those outside your inner circle, such as relationships present in employment situations, were previously found to increase the likelihood of engaging in informal reconstruction (Talbot et al. 2020). Therefore, households with ownership documents were likely those going through and then becoming jaded by the FEMA recovery process, and then of those households with ownership documents, those also with employed members were likely the households that had the social networks and financial stability gained through their employment to facilitate informal reconstruction.

Informal housing reconstruction is a complex but understudied phenomenon. While we know that housing type (e.g., informal housing, low-income public housing, or housing disconnected from utilities) can create a level of vulnerability (Hamideh and Rongerude

2018; Romero-Lankao et al. 2014), it has yet to be studied alongside socioeconomic vulnerabilities for its effect on recovery outcomes. Specifically in this study, 82% of the sample engaged in at least some level of informal housing reconstruction, exemplifying its widespread nature across all groups, regardless of vulnerability characteristics. In terms of the interaction effect between ownership and employment outlined in the regression model 3, the compounded nature of employment and ownership documents provides new insight regarding drivers and access to resources for informal reconstruction. While this is potentially counterintuitive based on previous results and current literature on vulnerability that suggests higher vulnerability leads to reduced ability to engage with formal recovery processes, it may suggest there are significant benefits of informal reconstruction that entice households to forfeit their formal status. Many homeowners in previous disaster scenarios and in the case of Puerto Rico have seen multiple benefits of using informality over formality, including quicker construction timelines, thus shorter timelines to return to normalcy, and an increased sense of agency and control over one's own recovery (Flinn et al. 2017; Viglucci 2018). Similarly, in this study, it was found that the group that is generally viewed as 'least vulnerable,' that is, those who were employed and had ownership documents, were the ones that engaged in higher levels of informal reconstruction. Therefore, we position informal reconstruction as an 'alternative' recovery outcome and not necessarily a form of vulnerability or a subpar or lesser option that exists due to a multitude of drivers in addition to the traditional explanation that informality is used as a last resort when no other option exists.

9 Conclusion and Implications

This study has identified socioeconomic vulnerability characteristics seen commonly in disaster literature and present in Puerto Rico after Hurricanes Irma and Maria, as well as their co-occurrences. Results from a series of logistic regression models suggest that respondents with higher levels of education have a lower odds of using informal reconstruction, compared to respondents with lower levels of education. Further, respondents that reported having ownership documents and at least one employed adult in the home, were the group with the highest odds of using informal reconstruction, compared to the three other possible groups. In general, these results show that socioeconomic vulnerabilities, including lack of ownership documents pre-disaster, shape a household's ability to recover from a disaster event, specifically in the area of informal housing reconstruction. Theoretical contributions include a proposition to include lack of ownership documents pre-disaster as an additional socioeconomic vulnerability indicator in the context of post-disaster recovery, in addition to the demographic and economic characteristics more traditionally included in the socioeconomic vulnerability framework. Results found significant results for the pre-disaster ownership variable, suggesting its interaction with other vulnerability variables to affect the recovery process.

An additional theoretical contribution is an extension of current literature analyzing the relationship between socioeconomic vulnerabilities and recovery outcomes, to consider informal housing as a measurable and significant outcome in the context of post-disaster reconstruction. To understand post-disaster reconstruction as a complex phenomenon, we need to consider all paths of recovery regardless of its existence within or outside of the official processes established for recovery. With this inclusive lens toward housing

recovery, we can move forward with inclusive disaster management and reconstruction planning.

Beyond understanding household socioeconomic vulnerabilities, it is important to note that effective institutional capacity is essential for adopting and enforcing building codes and other regulation. More research is needed in the areas of institutional capacity and informal housing to understand the political and organizational governance environments in Puerto Rico in which rural households navigate recovery and may influence use of informal housing reconstruction. Further, and suggested in the section above, further research is needed to understand the nature of informal housing in terms of potential categorization as a recovery outcome that perpetuates vulnerability. The results from this study suggest that it is the least vulnerable groups that were actually the most likely to engage in informal reconstruction, and there are many identified benefits to using informality during a recovery process. However, due to the structural concerns of informal housing, more research is needed to give a holistic understanding of the nature of informal housing as a recovery outcome.

Declarations

Ethical Approval This study was reviewed by the Iowa State University Institutional Review Board (IRB) to ensure ethical research with human subjects. This study is included as a modification of study number 18-111-00 and deemed exempt from full review. All survey data have been anonymized.

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