The Dilemma of the Tropics: Changes to Housing Safety Perceptions, Preferences, and Priorities in Multi-Hazard Environments

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ABSTRACT

This study seeks to understand how housing safety perceptions have changed after a specific hazard event, the 2019-20 earthquakes affecting the U.S. Caribbean island, Puerto Rico. The research team conducted and qualitatively analyzed fifty-two semi-structured interviews with households, informal builders, and individuals involved in formal construction on the island to understand risk and safety perceptions related to both hurricanes and earthquakes before and after the 2019-20 earthquakes. The study finds that, after the earthquakes, trust in informal construction processes decreased, trust in formal construction processes and self-efficacy increased, and perceptions of expected earthquake damage and views on the relative safety of building materials changed, including a notable shift to doubt the safety of concrete construction. Because household risk and housing safety perceptions directly affect decisions about safe construction materials and practices, it is critical to both understand these perceptions and investigate how these perceptions may change with the experience of a less frequent or familiar hazard event.

INTRODUCTION

With disasters growing in both frequency and severity of impacts due to rapid urbanization in hazard-prone regions and the effects of climate change (Dinan 2017), there is an increasing need to support resource-limited populations as they rebuild their houses and livelihoods after a hazard event. Resource-limited populations are both more likely to live in hazardous locations and less likely to have the resources or time necessary to rebuild and recover after a disaster (Fothergill and Peek 2004; Tierney 2006), making them more vulnerable in future disasters. Left without a house, the vast majority, frequently greater than 70%, of these disaster-affected, resource-limited households, begin the rebuilding process immediately, without external support (Parrack et al. 2014). This pressure to rebuild rapidly and inexpensively leads to households constructing non-engineered housing *informally,* potentially resulting in rebuilding with the same vulnerabilities as their previously damaged or destroyed houses. Here, we use informal construction to refer to construction that occurs without adhering to building codes or acquiring permits or formal review by architects and engineers.

To combat this pattern of reproducing vulnerabilities within the informal construction sector (Lyons 2009), many organizations and governments seek to encourage safer construction practices and "building back better" (Clinton 2006; Kennedy et al. 2008). However, these resilience-building programs are often implemented in the wake of a specific type of hazard event and thus frequently focus on the type of hazard event the community is most recently recovering from, rather than considering the multiple types of hazard events to which a house may be exposed to in multi-hazard environments. Different types of hazard events cause different housing failure modes and consequences, and, thus, an individual who builds a safer house for one hazard could end up increasing their house's vulnerabilities to other hazards. The 2010 earthquake in Haiti is a key example of the role of household hazard perceptions in a multi-hazard environment. Due to the frequency of devastating hurricanes in the Caribbean, and relatively less frequent earthquakes, informal builders Haiti developed safety perceptions and building techniques that were closely tied with their local understanding of hurricanes. As a result, the majority of houses in Haiti constructed during the

50 20th century were heavy, concrete structures built to withstand high winds and storm surge (Marshall et al.
51 2011; Mix et al. 2011). Unfortunately, the aftermath of Haiti's 2010 earthquake revealed that these
52 hurricane-resistant construction techniques exacerbated the damage and destruction from the less-frequent
53 hazard event, earthquakes. The effects of such an unexpected and less-frequent hazard event may lead to
54 changes in perceptions of risk and safety, creating a window of opportunity to construct housing that is
55 safer in *multiple* types of hazards.

56 Because hazard risk and safety perceptions influence what people build, this study seeks to understand how
57 housing risk and safety perceptions, preferences and priorities change with the experience of a severe, but
58 less-frequent hazard event. It is widely understood that peoples' views of safety and risk shift after they
59 experience a disaster (Wachinger et al. 2013), including ideas about which construction practices and
60 materials are safe. However, there is a dearth of research that has investigated how, in a multi-hazard
61 environment, perceptions of risk and housing safety change after experiencing different types of hazard
62 events, especially examining the change in household preferences and priorities after the occurrence of a
63 less-frequent hazard event. By better understanding how local views on the risks and safety of different
64 construction practices shift after a hazard event, it is possible to identify ways to encourage household
65 adoption of safer building practices and enhance the multi-hazard performance of houses built through the
66 informal construction sector.

67 **LITERATURE REVIEW AND POINTS OF DEPARTURE**

68 Despite a push to build upon local knowledge to construct safer houses after disasters, there is a lack of
69 understanding of what local knowledge exists around safe construction in multi-hazard environments, how
70 risk and safety perceptions change immediately following a hazard event, and how these shifts in
71 perceptions influence the informal construction sector. These perceptions of hazard frequency and severity
72 influence the actions households take to reduce disaster risk during rebuilding.

Understanding risk perceptions in multi-hazard environments

Risk perceptions are intuitive risk judgments that often rely on heuristics to enable individuals to weigh their risks to different hazards (Slovic 1987); these perceptions then influence an individual's desire to mitigate some risks over others. We argue, therefore, that to promote mitigation to hazard events in a multi-hazard environment, there is a need to investigate the risk perceptions of individuals with regard to each of the hazard events they may face. Knowing that individuals tolerate different levels of risk from a range of hazards, Henrich et al. (2018) investigated perceptions of earthquake risk compared to other hazards, including nuclear power and smoking. They found risk tolerance is impacted by factors including number of injuries and fatalities, amount of property damage, and whether or not this risk is taken voluntarily. More research is necessary, however, to understand the safety and risk perceptions individuals have regarding multiple types of *natural* hazards.

Further, there is not yet enough research on risk perceptions related to multiple types of hazard events in relation to housing safety, and how these perceptions translate to household ideas about the safety of their houses and modifications that can be made to improve safety. Previous studies of reconstructed and repaired houses have assessed household satisfaction with housing in general (e.g., showing overall ideas of residential satisfaction with living conditions in terms of size, location, and available public facilities). However, they have not investigated household satisfaction in the context of housing safety for future hazards. One study of multi-hazard perceptions in the Philippines found that households perceived their houses to be more vulnerable to typhoons than earthquakes, even though they lived in areas with high seismic risk (Venable et al. 2020). Another study investigated Haiti's 2010 M_w 7.0 earthquake, finding that traditional construction practices, which used primarily wood, better withstood the earthquake than the more modern practices. However, this traditional wood construction was rare in Haiti because the informal construction sector shifted towards heavy concrete blocks and slabs to withstand frequent Caribbean hurricanes (Audefroy 2011). This example of Haiti reveals how shifts in the informal construction sector to address the risks of certain types of hazard events, hurricanes, could lead to increased structural

vulnerabilities to another type of hazard event, earthquakes (Marshall et al. 2011; Mix et al. 2011). Research is needed to understand how risk perceptions change immediately following a less-frequent disaster among households and builders, amid wide-spread fear and uncertainty. These efforts need to focus on the informal construction sector within which most resource-limited households act.

Many studies have linked past disaster experience and risk perceptions. For example, some literature has found that recency bias, or the cognitive bias that explains the tendency to put a stronger emphasis on more recent events, influences decision making and leads disaster-affected people to estimate a higher probability of occurrence for types of hazard events that occurred recently (Merz et al. 2015). Thus far, literature has examined how recency affects perceptions of risks from hazards in the context of one type of hazard event, flooding (Kousky and Shabman 2015; Vásquez et al. 2018) or another, earthquakes (Guo and Li 2016). These studies indicate that, when exposed to disasters through personal experiences or extensive media coverage, individuals are more likely to be able to imagine the negative impacts of a hazard and thus are more likely to view future disasters as more probable and dangerous. Prior disaster experience has also been shown to be an influencing factor of whether or not Florida households chose to mitigate their risk to hurricanes through shutter usage (Peacock et al. 2005). Studies have called for further investigation of the relationship between perceived risk and willingness to act and prepare for hazards (Wachinger et al. 2013).

The need to investigate changes in the post-disaster window of opportunity

Disasters cause disruptions to society and thus create "windows of opportunity" for both positive or negative changes (Birkland 1997). These changes can include shifts in societal views related to safety and risk after these devastating events (Haigh 2010), as well as changes to design and construction of the built environment. In this context, one study sought to uncover the changes to individual judgments of risk in New Zealand after an unexpected hazard, the 2011 Christchurch earthquake (McClure et al. 2015). By having respondents of varying hazard exposure and expectations elaborate on their judgments of risk and recall their experiences before the earthquake, this study revealed that, after the earthquake, individuals

were more likely to expect earthquakes in the future and more willing to make changes to prepare for these future earthquakes.

During this window of opportunity, there is also evidence that governments may change and update building codes and code enforcement to recognize and respond to these risks, indicating formal, organizational, and policy level changes. However, these efforts towards code development and enforcement vary widely (Nguyen and Corotis 2013). For instance, Chile developed its first building code in 1930 in response to a devastating earthquake impacting the country two years prior. The country went on to revise their codes several more times over the subsequent 80 years, each revision following a major earthquake, while also moving towards wood frame and reinforced masonry construction (Kovacs and Institute for Catastrophic Loss Reduction 2010). However, in resource-limited areas with weak regulatory enforcement of construction, households do most rebuilding informally, without adherence to these government building codes.

Shifting perceptions in the informal construction sector

Further research is necessary to understand how changes in the informal construction sector occur in resource-limited communities after a disaster. For example, after a 1988 earthquake, Nepal developed building regulations that acknowledge informal construction practices and non-engineered structures, providing a list of mandatory "rules of thumb" for builders to follow. Despite the efforts to formalize the sector with these regulations (Arendt et al. 2017), there was a lack enforcement and little awareness of the existing risk and safety of housing in earthquakes in Nepal's construction industry, leading to limited adoption of these safer building practices and contributing to the devastation from the 2015 earthquake (Chmutina and Rose 2018).

It is important to investigate how experience with different types of hazard events affect disaster risk and housing safety perceptions, and whether these informal builders feel increased self-efficacy or fatalism. These changes to self-efficacy and fatalism are important to recognize as perceived self-efficacy increases an individual's perceived ability to prepare for future hazard events, while fatalism, or feelings of

147 helplessness regarding the possibility of preparing for future hazard events, has been found to discourage
148 people from preparing for hazard events, particularly earthquakes (McClure et al. 2001; McClure et al.
149 2007; Turner et al. 1986). This study investigates how perceptions of safety, including local understanding
150 of safe construction and risk perceptions related to their houses, shift among resource-limited communities
151 who rebuild immediately and informally after a disaster. Specifically, this study will uncover changes to
152 safety and risk perceptions among households who live in informally constructed houses and individuals
153 involved in the informal construction sector after the experience of a less-frequent hazard—an earthquake—
154 in the multi-hazard environment of Puerto Rico, a U.S. territory in the Caribbean.

155 **CONTEXT**

156 The Caribbean is vulnerable to both hurricanes and earthquakes. As a result, researchers have called for
157 additional studies on perceived risk and how perceived risk relates to mitigation and resilience building
158 (Martin et al. 2016). Our study focuses on Puerto Rico, which experienced a series of earthquakes and
159 aftershocks from late December 2019 through early January 2020, while still recovering from devastating
160 Hurricanes Irma and Maria in 2017 (U.S. Geological Survey 2020).

161 **Puerto Rican construction practices**

162 An estimated 700,000 of the roughly 1,200,000 total houses in Puerto Rico have been informally
163 constructed (Hinojosa and Meléndez 2018). With a lack of regulatory enforcement on construction (Nonko
164 2017), the typical construction of a house in Puerto Rico involves family members and neighbors providing
165 labor and building without supervision or inspections. Preliminary discussions with contractors and
166 households revealed that these informal, non-licensed builders often seek the advice of local hardware store
167 employees and neighborhood handymen. Within this study, we refer to these groups as those involved in
168 the informal construction sector.

169 One common form of housing is heavy concrete construction. These houses often consist of a first floor
170 with a reinforced concrete frame with concrete-block masonry infill walls, topped with a flat reinforced
171 concrete slab roof that allows for future expansion of either a concrete or light-framed, wooden second

story (Prevatt et al. 2018). Many families also live in single-story wooden houses with corrugated galvanized iron (CGI) roof panels (Cruzado and Pacheco-Crosetti 2018). The prevalence of wooden and concrete houses varies across the island, likely due to the severity of Hurricane Maria's winds across much of the eastern and northeastern regions, which primarily damaged houses with wooden roof structures.

Hurricane Maria

Over the past thirty years, Puerto Rico has experienced several devastating hurricanes, making hurricane risk a top concern for government and households alike. These hurricanes included Hurricane Hugo in 1989 and Hurricane Georges in 1998, which in particular damaged or destroyed over 100,000 houses (Enterprise Community Partners 2019). Hurricane Maria, however, was an unprecedented disaster in terms of impacts on housing, disruptions to communication, electricity, and lives lost (Hinojosa and Meléndez 2018).

The hurricanes that devastated Puerto Rico in September 2017, Irma and Maria, damaged or destroyed roughly 400,000 houses, or one-third of the total houses on the island (Brown 2018). Hurricane Maria was a Category 4 storm that hit Puerto Rico just two weeks after Hurricane Irma (Category 5). After Hurricane Maria, only 40% of applications for assistance were accepted by the U.S. Federal Emergency Management Agency (Acevedo 2018) and most of the approved funds for household assistance were used to satisfy immediate needs for water, food, or power. In addition, many of the damaged houses were built on inherited land, for which many families did not hold the title, often discouraging them from attempting to access formal permitting process and resulting in them not qualifying for government assistance (Acevedo and Pacheco 2018). This lack of external support left households in Puerto Rico to repair and rebuild their houses using their own resources, most often through the informal construction sector.

The 2019-20 earthquakes

The majority of the island felt at least the shaking and associated power outages of the 2019-20 earthquakes off the southwestern coast of Puerto Rico, particularly the M_w 6.4 earthquake that occurred on January 7, 2020. Before this series of earthquakes and aftershocks, the last major earthquake to impact Puerto Rico was the 1918 San Fermín earthquake and tsunami, which was a M_w 7.1 earthquake that generated a tsunami

with waves up to 20 feet, causing 116 casualties, damaging or destroying over 10,000 houses, and costing over $4 million in damages (Enterprise Community Partners 2019). Following this hazard event, the U.S. Army Corps of Engineers, Commissioner of the Interior, and a special earthquake commission were responsible for revising Building Regulations in Puerto Rico (Enterprise Community Partners 2019). However, as described above, a large portion of construction on the island occurs outside this regulatory structure.

The 2019-20 earthquakes directly affected over 40,000 people (*HAZUS Results Dashboard for Puerto Rico Earthquakes* 6.4 2020), with some estimates indicating that 8,000 houses in the southwestern region of the island required critical repairs, leaving 2,500 uninhabitable until the repairs are completed (Miranda et al. 2020; Robles and Rodriguez 2020). In addition to these houses, one school was severely damaged in Guánica, Puerto Rico, causing immense fear across the population and distrust in the building codes and designs used to construct schools. The tension was further increased in the days following the earthquake, as the U.S. Geological Survey informed residents on January 16, 2020, that aftershocks had a 54 percent chance of reaching a magnitude of 5 or higher in seven days ("As Aftershocks Continue in Puerto Rico, USGS Supports Quake Recovery" 2020). After these earthquakes, schools were closed for inspection, and only twenty percent of the island's schools were open by the end of January (Coto 2020). Even as schools gradually reopened, parents continued to distrust any government-built or approved buildings and chose instead to live in tents outside of their original houses, even if the government inspectors deemed them as safe (Robles and Rodriguez 2020). It is critical to understand how this shrinking trust, even in buildings that had been constructed formally, has affected housing safety perceptions on the island.

METHODS

To evaluate risk and safety perceptions, preferences, and priorities for housing design and construction before and after the 2019-20 earthquakes, interviews were administered by local research assistants, transcribed, and analyzed qualitatively with QSR NVivo. Semi-structured interviews asked households and those involved in both informal and formal construction processes about (1) trust, regulations, and

supervision of construction; (2) hazard and risk perceptions, including expected damage from hurricanes and earthquakes; (3) safe and unsafe construction practices, including relative safety of different building materials; and (4) strategies for increasing the safety of houses for both hurricanes and earthquakes. Questions about hurricanes focused on wind rather than storm surge concerns. All interviews were completed by local research assistants in English or Spanish, depending on the preference of the interviewee. All data collection and analysis were completed in compliance with our Institutional Review Board protocol (#19-0337) to retain the safety and privacy of our interviewees.

Data collection

In summer 2019, we conducted semi-structured interviews to collect pilot data for a study regarding local perceptions of housing safety in multi-hazard environments. The team completed thirty interviews from July to August 2019 across three distinct groups: households, formal builders, and informal builders. This pilot data included fifteen household interviews; seven interviews with people with experience working in formal post-disaster reconstruction processes on the island, including civil engineers and reconstruction program staff; and eight interviews with people with experience working in the informal construction sector on the island, including un-licensed builders and hardware store workers who frequently advise on or otherwise support informal construction of houses. Initial interviews were conducted using convenience and snowball sampling techniques in the municipalities of San Juan, Toa Baja, Loíza, Yabucoa, Humacao, Caguas, and Barranquitas. These municipalities were selected for initial interviews due to their varied topographies and exposure to Hurricane Maria. After 30 interviews, we reached saturation, the point when we no longer received new responses to interview questions. These interviews occurred during hurricane season.

During these interviews, we asked questions about the process of constructing a house prior to Hurricane Maria, the reconstruction process after Hurricane Maria, and hurricane and earthquake risk perceptions. We asked interviewees a series of questions to understand general earthquake risk perceptions, including questions about perceived likelihood of occurrence; methods of preparing for or otherwise acting during an

earthquake to remain safe; whether interviewees had experienced, or known anyone to experience, earthquake damage; and whether they would change anything about their houses to make it stronger for an earthquake. As an example, we asked, *"If you built this house yourself, or made any of these additions yourself, can you take me through the process of how you learned to design and build this house?"* and *"What would you change, if anything, about your house to make it safer for a future earthquake?"*

After the 2019-20 earthquakes severely impacted the island, the research team returned to the island and completed another series of semi-structured interviews to understand changes in risk perceptions and housing construction preferences and priorities. We began these interviews in early February 2020, about one month after the earthquakes. We immediately noticed shifts in whom people trusted about construction, what damage was expected from earthquakes, the perceived relative safety of construction materials and methods, and increased discussion of ideas to build safer, more earthquake-resistant houses. We completed 22 more semi-structured interviews, repeating the questions asked in Summer 2019, with nine households, three people involved in the formal construction sector, and ten people with experience working in the informal construction processes on the island. Again, we used convenience and snowball sampling methods to conduct these interviews and reached saturation. Interviews were conducted in the municipalities of San Juan, Yabucoa, Humacao, Naguabo, and San Germán to capture a range of hazard experience levels with both Hurricane Maria and the 2019-20 earthquakes. Table 1 shows a count of interviewees from each subject group, before and after the 2019-20 earthquakes.

Analysis

Semi-structured interviews were translated, transcribed, and qualitatively coded to establish key themes before and after the 2019-20 earthquakes. In total, we coded 1143 audio minutes of interviews from the July 2020 interviews and 872 audio minutes from the February 2020 interviews. We inductively coded pre-earthquake interviews by categorizing, grouping, and evaluating references to trust, regulations, and supervision; hazard and risk perceptions, including expected damage in disaster events; the relative safety of construction practices and materials; and methods of increasing the safety of houses for both hurricanes

and earthquakes. For example, when coding pre-earthquake interviews, we first developed parent nodes, such as the theme of *"distrust in informal builders,"* which included discussions of distrust in the safety of informal construction, corruption in the informal construction sector, and examples of unsafely constructed informal houses. Alternatively, discussions of general trust in all builders, both formal and informal, were excluded from this parent node. We then added child nodes for the subcategories of reasons for this distrust, such as *"taking shortcuts to save money,"* and *"lack of construction knowledge."* We then used these parent and child nodes that emerged inductively in pre-earthquake interviews, to deductively code entire post-earthquake interviews, searching for changes among these themes before and after the earthquakes.

We incorporated validity and design measures for qualitative data from Yin (2017). In particular, we followed a research protocol for data collection and analysis to ensure replicable results, including asking the same semi-structured questions across interviews and using a coding dictionary and protocol for analysis. We checked for rival explanations (Yin 2017) for our results to ensure that the cause for the changes in perceptions was the 2019-20 earthquakes by asking the interviewees the reasons why and how their ideas of risk or safety have changed.

FINDINGS AND DISCUSSION

Findings from this series of semi-structured interviews provide insight into changing perceptions about trust in both informal and formal construction processes, expected earthquake damage, relative safety of common building materials and design decisions, and self-efficacy among individuals who have and have not experienced earthquakes. Before the 2019-20 earthquakes, households in Puerto Rico were primarily concerned with one hazard, hurricanes. During our interviews in July and August of 2019, all interviewees were still mentally and physically recovering from the devastation caused by Hurricane Maria, less than two years prior. During our interviews after the earthquakes, in February 2020, households were primarily concerned with earthquake risk, with most interviewees intensely monitoring the latest aftershocks and sleeping by their doors for a quick escape with packed emergency bags if necessary.

Changes in trust and perceptions of regulations and supervision

Interviewee responses to our questions revealed a notable shift in trust *from* informal *to* formal builders and construction processes after the 2019-20 earthquakes. Interviewers did not ask directly about trust, and, thus, these responses came organically from questions like, "*Can you describe what a safe house looks like? How would this safe house be built*?" and "*Can you describe a house that is less safe than yours? What makes it less safe*?" We qualitatively coded trustworthy information sources and individuals as those identified as having true and reliable messaging that "demonstrates competence and honesty by conveying accurate, objective, and complete information" (Renn and Levine 1991). For instance, when interviewees described whom they believe is willing and able to offer safe building advice or to assist or supervise with building a safe house, we coded these discussions as "*trust."* Alternatively, we coded descriptions of whom interviewees believed were *not* willing and able to offer this safe guidance or assistance as "*distrust."* Table 2 summarizes the results for the discussion of informal and formal construction processes among interviewees before and after the earthquakes.

Distrust in the informal construction sector

Before the 2019-20 earthquakes, 30% of interviewees discussed their distrust in informal construction processes when asked about the construction of their houses and when asked to compare the safety of their houses to any other houses in their communities. All of these interviewees elaborated on this distrust by recalling stories of informal contractors *"cutting corners"* or *"taking shortcuts"* while constructing houses without permits. One household representative explained, *"I don't think [the informal builders] did a very good job building [the house] from the beginning. So that's why it collapsed in Hurricane Maria. They use cheap materials and just to do a faster job."* Thus, this distrust in the informal construction sector was often linked with statements of informal builders saving money or time in the construction process.

After the earthquakes, incidences of interviewees bringing up feelings of distrust towards informal builders rose from 30% to 95% (See Table 2). Similar to discussion before the earthquakes, the majority of interviewees explained this distrust by mentioning that informal builders (sometimes called "chiveros") take shortcuts throughout the building process to save money. One hardware store employee interviewed

after the earthquakes explained the sentiment this way: *"the term chivero is very negative because people think that chiveros are the ones that do a bad job. They have no experience at all, they do it to get the money."* Overall, analysis of the post-earthquake interviews revealed many interviewees had doubts about the cost-cutting measures of informal builders.

However, in addition to this discussion, half of the interviewees attributed their distrust in informal construction to these builders not having formal training or education on safe construction methods. For example, one individual working within the formal construction sector on the island explained their skeptical feelings about the safety of the usual Puerto Rican informal construction process, including not trusting the *"typical neighbor"* , saying, *"I think there is a need for them to learn how to build more resilient and stronger structures to face any environmental challenge."* In other words, this interviewee was expressing doubt in the safety of the construction that is completed by these neighbors, community members, or friends who typically help or guide others through the process of building a house informally.

The interviews also revealed that several informal builders acknowledged how learning by "trial and error" has compensated for formal knowledge. As one handyman explained, *"truly when you acquire a skill by practicing all the time, you do things and fail. Trial and error."* For decades, informal builders on the island had been able to learn lessons from their friends, neighbors, and family members, who had learned to build to resist annual hurricanes. While they learned over time to improve their practices to build hurricane-resistant houses, these builders did not have the opportunity to learn in that same way from earthquakes, contributing to the observed failures and the distrust of others.

Importance of supervision of housing construction

While no interview questions directly asked about construction supervision, there was a notable increase in responses that discussed the need for regulatory supervision of housing construction after the 2019-20 earthquakes. Before the earthquakes, only five out of the 30, or 17%, of interviewees mentioned the need for formal contractors to oversee construction projects; after the earthquakes, this number rose to 73% of

interviewees (See Table 2). Specifically, interviewees discussed the need for people knowledgeable in construction to oversee the process and ensure builders are using safe materials and methods, as well as not taking shortcuts that compromise safety to save money or time. As an example, after the earthquakes, one builder expressed his frustrations working within the informal construction sector without supervision, stating, "*everything is going to fail without supervision*" because "*there are times when I know we have to use ten rebars but my boss uses six or seven rebars and I try to make them listen to me! But I can't, because my boss's role is not the same as mine.*" Interviewees emphasized the need for supervision of both informal and formal construction projects. After the earthquakes, multiple interviewees involved with both the formal and informal construction sectors argued that even formal construction projects with appropriate licenses and permits need additional supervision to ensure safety. For instance, one hardware store manager explained what he often sees happen when people *do* choose to build through the formal permitting process by saying, "*people have to get a permission from the government and pay for it, obviously, but no one comes to check the process. They don't come to the field to check what is happening on site*. *They just give the permit and people do whatever they want.*" This process of permitting without regulatory supervision or enforcement of building codes discourages many households from building formally, leading them to continue to hire cheaper, local builders they trust to build housing informally.

With these shifts towards trust in formal construction processes, including the desire for increased supervision of building processes, there was also a notable increase in the number of interviewees mentioning their desire to seek guidance from engineers and architects on construction. Before the earthquakes, only 10% of interviewees mentioned this need for expertise and guidance and all were already involved in formal construction processes as engineers themselves or reconstruction program staff working alongside these professionals. After the earthquakes, the percentage of interviewees mentioning the value of advice from engineers and architects rose to 77% (See Table 2). This large shift towards the desire for formal construction processes was marked with quotes like, "*if people follow these codes and consult engineers, all these problems wouldn't exist*." Another household representative stated, *"Everybody is*

going to cut corners, especially if you don't have an engineer supervising the construction." Overall, this analysis revealed growing doubt of interviewees in informal construction processes and increased willingness to seek formal construction guidance after the 2019-20 earthquakes.

Impact of past-disaster experience on expected earthquake damage

This study also revealed a notable difference in views on expected earthquake damage before and after the 2019-20 earthquakes. In both July 2019 and February 2020, we asked interviewees, *"Have you or anyone you know ever had a house damaged by an earthquake? If so, can you describe what that earthquake damage looked like?"* Responses were assigned this code in cases where interviewees elaborated on potential earthquake damage while answering additional questions about building an earthquake-safe house, including responses to the questions, *"Can you describe what a safe house is like for an earthquake?"* and *"Can you describe a house that is more or less safe than yours in an earthquake?"* Table 3 summarizes the results for the discussion of expected earthquake damage.

From tsunami risk to concrete damage

When asked to describe earthquake damage, a larger percentage of interviewees in the group interviewed before the 2020 earthquakes immediately mentioned tsunami effects, like flooding damage and a loss of life, rather than mentioning potential structural shaking damage. Interviewees made statements like, *"I don't want to think about that… I live next to the beach, I'm just going to die."* In July 2019, several interviewees mentioned warnings from the government and other media about tsunami risk. One referenced how a lack of awareness about tsunami danger led to loss of life after the 1918 earthquake and tsunami in Mayaguez, Puerto Rico, stating *"There was a tsunami in Mayaguez where people died because of ignorance because the sea was distant, nobody knew what it meant, people went fishing, and then the waves reached the Mayaguez square."* The 2019-20 earthquakes did not result in any tsunamis, and the number of interviewees who mentioned this tsunami danger decreased from 40% from the first round of interviews to 9% after the 2019-2020 earthquakes (see Table 3).

With this recent earthquake experience, people grew to doubt the structural performance and strength of materials particularly related to reinforced concrete structures. We did not specifically ask questions about concrete damage in earthquakes, but we did ask households if there were any changes they would make to their houses to make them safer for earthquakes. When asked to describe earthquake damage, only 27% of those interviewed before the earthquakes mentioned the potential risk to reinforced concrete structures, and most of these interviewees worked as engineers or within formal construction processes. When looking at the group of interviewees after the 2020 earthquakes, the percentage of interviewees mentioning potential earthquake damage to concrete rose from 27% to 100% (see Table 3). Thus, unlike the July 2019 interviews, every person interviewed with experience with an earthquake brought up potential damage to concrete houses in the interview. For example, one interviewee who had experienced the January 7, 2020 earthquake's shaking explained*, "The fear here is with the concrete house, everyone is afraid.*" This fear of concrete housing construction marks a drastic change in housing safety perceptions after the earthquakes. However, the builders who worked within the formal construction sector did not show changes in perceptions before and after the earthquakes. Instead, these formal builders told us about the changes they had observed in informal builder and household safety perceptions.

Some of the most dramatic destruction to take place, and be shown across the media, featured the soft-story failure of reinforced concrete columns (stilts), in communities near the epicenter of the January 7th earthquake. Before the earthquakes, only one interviewee mentioned potential damage to columns, citing his direct experience with earthquakes affecting these columns in the past when he said *"There was a tremor here nine years ago… That's why I said it's important to reinforce the stilts. Look at the floor; there's cracks."* Fifty-five percent of the February 2020 interviewees elaborated on more earthquake damage to concrete columns or stilts. One interviewee stated, *"Before the earthquake, you knew you had to build tall stilts to avoid the sea water, but now that's also dangerous because if you don't take the right measures, they can crush down easily."* Interviewees with earthquake experience doubted the structural integrity of concrete columns, or stilts, a common construction technique in Puerto Rico this is used to avoid flooding.

From fatalism to self-efficacy?

With this shift after the earthquakes to a wider understanding of specific damages that could occur to houses in an earthquake, there was also a notable change in the number of interviewees who mentioned how they could build an earthquake-safe house. This change was especially evident among household interviewees, who did not have construction experience. Both before and after the earthquakes, we asked interviewees the questions, "*Would you change anything about your house to make it safer for an earthquake?"* and *"Can you describe what makes a house safe for an earthquake?"*

Most interviewees from July 2019, or 63% of those without earthquake experience, brought up feelings of hopelessness and fatalism regarding earthquake safety, with only 33% mentioning ideas for making their houses safer, and the remaining interviewees dismissing the question. These fatalist responses included thirteen out of the fifteen, or 87%, of household interviewees before the earthquakes. These fatalist responses included statements like, *"if a big earthquake occurs, no house would resist," "nothing is safe for an earthquake,"* and, *"if something strong happens, there is nothing anyone can do to prevent it."* A smaller proportion, 23% of total interviewees, and only 33% of household interviewees, who had experienced the 2020 earthquakes made these fatalist statements.

In addition, the number of interviewees able to describe steps they could take to build a safer house for earthquakes notably increased among the group who had experienced an earthquake, from 33% to 91%. All of these statements referenced the damage they had seen in images in the media after the earthquakes. The interviewees proposed actions to build safer housing that included consulting a structural engineer and building concrete with additional reinforcing bars. For instance, one hardware store employee stated that households are *"building the columns wider, they are reinforcing them with concrete and steel rods."* Interviewees recognized the value of additional reinforcement in their reinforced concrete houses.

These findings show how people who have a deeper understanding of expected damage from earthquakes may also have an increased understanding of how they could build safer houses. More household

representatives interviewed after the earthquakes, specifically, made comments about which houses they could expect to do well and which they expected to do poorly in the event of another earthquake. Several people working within the informal and formal construction sectors on the island mentioned homeowners having increased agency to improve their earthquake safety. One member of a community-based organization working on outreach projects across the island told us that they had hosted earthquake preparedness workshops prior to the earthquakes that had dismal attendance, saying, *"before the earthquake we were providing workshops about tsunamis, earthquakes, and we didn't have enough participation of the community."* Yet, after the earthquakes occurred, the workshops were full. This interviewee went on to describe the overflowing workshop they held in mid-January 2020, saying, "*after the earthquake hit us, people were standing outside of the community center"* trying to learn how to stay safe in the face of this newly experienced hazard.

Shifting ideas about relative safety of materials

The responses also indicate a change in how interviewees viewed the relative safety of housing materials and systems. Table 4 shows the relative frequencies of interviewee responses regarding the relative safety of concrete and wood. These responses were to the questions, "*Can you describe what a safe house looks like? How would this safe house be built*?" and "*Can you describe a house that is less safe than yours? What makes it less safe*?" The majority of interviewees made comparisons between concrete and wood without being prompted by the interviewers. For example, when asked about hurricane damage to her house, one interview said *"we did think the house was going to fall, even though it was built with cement. I didn't even want to think about the people whose houses were built with wood. We were afraid about our lives."* Table 4 shows the results for the discussion of the relative safety of concrete and wood.

Safety of concrete vs. wood

Prior to the 2019-20 earthquakes, the majority of interviewees discussed the relative advantage of reinforced concrete houses in terms of hurricane resistance. One interviewee, for example, explained, *"concrete… it's*

better than a wood house here… basically every 5 or 6 years, there's always a hurricane hitting us. That's why you'll see most of the houses in concrete." Before the earthquakes, 83% of interviewees expressed that households preferred fully (reinforced) concrete houses in response to any questions about building safe houses for hurricanes or earthquakes. For example, when asked about safe construction materials and practices, one interviewee stated, *"as a hardware store manager, I sincerely always recommend to build in concrete. The majority of people want a concrete house."* After the earthquakes, however, the number of people who stated their preference for concrete construction, as a response to any interview question, dropped from 83% to only 36% of interviewees (see Table 4).

In addition, several individuals working within both formal and informal construction sectors expressed frustrations in the typical Puerto Rican household misconception about concrete's perceived nearly infinite resistance without regular maintenance. For example, before the earthquakes, one practicing civil engineer on the island stated his frustrations that households think that they can *"build with concrete because [they] will never have to do maintenance, and [they] don't build with wood because it's worthless, it wouldn't resist a hurricane. That's incorrect."* Several engineers and architects also mentioned the idea of Puerto Ricans, like others in the Caribbean, preferring to *"build heavy"* with primarily concrete construction to resist regular hurricanes. This was clear from the household interviews conducted in summer 2019, where households repeatedly mentioned the lightness of wood roofs, and how they frequently blow away in storms. For example, one interviewee explained that *"the wooden roofs flew off of every house in the community"* during Hurricane Maria. Findings from this qualitative analysis suggest a shift towards a more nuanced understanding of the specific damages that happen to both individual building components and structural systems, rather than the focusing on primary building material alone. For instance, after the earthquakes, households more readily discussed the details involved in constructing a safe wooden house, rather than simply dismissing all wooden houses as unsafe. These interviewees elaborated on things like the specific spacing between members and types of connections in wooden roofs that could lead to a hurricane-resistant wooden house, like the use of hurricane straps and screws rather than nails.

The dilemma of the tropics

Several interviewees described the gradual shift from predominantly wood to more reinforced concrete construction with Hurricanes Hugo in 1989, Georges in 1998, and then Irma and Maria in 2017. For example, when asked about changes to safety perceptions over time, one interviewee stated that, after Hurricane Hugo specifically, there was a change "*from wood houses to concrete."* However, this study shows a clear shift towards more individuals questioning the performance of reinforced concrete construction after the earthquakes. Interestingly, more than half of the post-earthquake interviewees described the fact that they still trusted concrete more for hurricane resistance but thought of wood construction as safer for earthquakes. There was a notable increase in the number of people describing this contradiction, with none explaining this before the 2019-20 earthquakes and 13 people, or 59% of interviewees, bringing this up in interviews after the earthquakes. One interviewee stated, *"I prefer my house in concrete, but in case of an earthquake, you have to look for something more… a very well-constructed wooden house."* After the earthquakes, one interviewee described, *"That's the dilemma in the tropics. Because, you're safe in a concrete house for a hurricane but not for an earthquake. So, we have to find a happy medium."* This is the dilemma of constructing a house that is safe for both hurricanes and earthquakes with limited access to resources or formal guidance.

LIMITATIONS

This study advances knowledge on how risk and housing safety perceptions change immediately after a less-frequent and less-familiar hazard event in a multi-hazard environment, but, as with any study, it has limitations. First, we conducted the initial July 2019 interviews as pilot interviews before the 2019-20 earthquakes. These pilot interviews were for a study comparing local perceptions of housing safety and multi-hazard risk and engineering performance assessments. We focused on areas in Puerto Rico most affected by Hurricane Maria and did not interview anyone in the most earthquake-affected regions of the island. The earthquakes that occurred provided a new opportunity to conduct this study. Soon after, we returned to the island, using the same interview questions, to investigate changes in perceptions. On this

trip, we again focused on the municipalities along Hurricane Maria's path, mostly in the northeastern region of the island. While the research team had planned on additional interviews in communities more severely affected by the earthquakes, the Covid-19 pandemic and associated lockdowns began and we were unable to conduct these interviews. We considered only wind effects from hurricanes, not storm surge or flooding.

We note also that the semi-structured interview questions did not ask explicitly about trust in different groups (i.e., informal builders, engineers, or architects) or the relative safety of concrete and wood. Instead, interviewees brought up these topics independently, discussing their ideas in relation to other interview questions about their risk and safety perceptions. While this was advantageous, as we saw these themes arise repeatedly and organically through the semi-structured interviews, this presents limitations in the analysis of these responses because these themes did not arise through the same, structured questions in every case. Furthermore, we did not interview the same people before and after the 2019-20 earthquakes. Thus, these results should not be taken as precise indications of beliefs of the population, but instead used only to observe general trends in changing perceptions from before to after the earthquakes.

CONCLUSIONS

To promote disaster resilience of resource-limited communities who build through primarily the informal construction sector, this study set out to better understand the risk and construction safety perceptions of households and those working within the construction sector in Puerto Rico. Particularly, we investigated the changes to housing risk and safety perceptions in communities that had experienced the devastation of Hurricane Maria before and after the 2019-20 earthquakes. We interviewed households, informal builders, hardware store employees who provide advice to informal builders, engineers, architects, and reconstruction program staff before and after the earthquakes to identify shifts in these perceptions, and thus reveal areas of notable change. To identify shifts in perception after this less-frequent, less-anticipated event, we asked interviewees about their hazard and risk perceptions, expected damage from hurricanes and earthquakes, safe and unsafe construction practices, and relative safety of building materials.

Our findings identified changes to how households were discussing trust in both formal and informal

543 construction, expected earthquake damage, ideas about how to build safe houses, and relative safety of
544 reinforced concrete and wood. From before to after the 2019-20 earthquakes, there was an evident shift
545 from interviewees trusting to distrusting these informal construction processes and expressing the need to
546 follow building codes and supervision of housing construction. After the earthquakes, individuals also
547 changed the way they discussed potential earthquake damage, moving from a focus on tsunami risk in July
548 2019 to a focus on risk of concrete construction, specifically inadequately reinforced and designed concrete
549 columns, in February 2020. This growing understanding of the risk to concrete structures led several
550 interviewees to discuss the *"dilemma of the tropics,"* in which households feel torn between building
551 concrete houses to resist frequent hurricanes or wooden houses to withstand less-frequent, but potentially
552 devastating Caribbean earthquakes. Finally, this study revealed a decrease in fatalist statements about
553 earthquakes. Before the 2019-20 earthquakes, interviewees were hesitant to discuss earthquake risk,
554 offering fatalist statements about how there was nothing they could do to make their houses earthquake
555 safe. The number of fatalist statements lowered after the earthquakes, due to interviewees observing what
556 houses were *not* damaged in the earthquakes. With this shift away from fatalism, households after the
557 earthquakes were more likely to seek advice from engineers and architects to better understand safe
558 buildings. Overall, interviewees explained that households were more willing to invest time and money in
559 making sure their houses were earthquake-safe.

560 The findings of this study reveal how drastically risk and safety perceptions change following a less-familiar
561 hazard event. To understand the changes to the informal construction sector following a disaster, it is critical
562 to investigate the discussions about safe and unsafe building practices within resource-limited communities
563 immediately following a disaster. Particularly, this study reveals that households are more motivated to
564 learn about building safer houses during this post-disaster window of opportunity. Findings also reveal the
565 topics organizations and governments should focus on when working to enhance community capacity
566 during this post-disaster window of opportunity for change, such as providing guidance from trusted
567 engineers and architects and discussions of the relative safety of common materials.

DATA AVAILABILITY STATEMENT

Some or all data used during this study are proprietary and confidential in nature and may only be provided with restrictions (e.g., anonymized data). This includes interview data at a level of detail in which individuals and their responses to any interview questions can be identified. Redacted, coded data from interviews are available from the corresponding author upon request.

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711 **TABLES**

712 **Table 1.** Count and relative frequency of interviewees from each subject group

Date and Num. of Interviews	*Households*	*Formal Construction*	*Informal Construction*
July 2019: Pre-Earthquake N = 30	15 (50%)	7 (23%)	8 (27%)
February 2020: Post-Earthquake N = 22	9 (41%)	3 (14%)	10 (45%)

713

714 **Table 2.** Change in count and relative frequency of interviewees discussing supervision, guidance, and

715 trust before and after the earthquakes

Date	*Interviewees discussing distrust in (any or other) informal builders (%)*	*Interviewees discussing need for construction supervision (%)*	*Interviewees discussing their desire for guidance from engineers and architects (%)*
July 2019: Pre-Earthquake N = 30	9 (30%)	5 (17%)	3 (10%)
February 2020: Post-Earthquake N = 22	21 (95%)	16 (73%)	17 (77%)

716

717 **Table 3.** Change in count and relative frequency of responses describing expected earthquakes damage

718 before and after the earthquakes

Date	*Discussing tsunamis as the main danger, or cause of damage, from earthquakes (%)*	*Discussing earthquakes causing damage to concrete structures*	*Discussing earthquakes causing damage to concrete columns or stilts, specifically (%)*
July 2019: Pre-Earthquake N = 30	12 (30%)	8 (27%)	1 (3%)
February 2020: Post-Earthquake N = 22	2 (9%)	22 (100%)	13 (59%)

719

720 **Table 4.** Change in count and relative frequency of responses describing relative safety of concrete vs.

721 wood before and after the earthquakes

Date	*Stating preference for concrete construction for earthquakes and hurricanes (%)*	*Stating preference for wood construction for earthquakes and hurricanes (%)*	*Stating preference for concrete for hurricanes and wood for earthquakes (%)*
July 2019: Pre-Earthquake N = 30	25 (83%)	5 (17%)	0 (0%)
February 2020: Post-Earthquake N = 22	8 (36%)	1 (5%)	13 (59%)

722