Building back towards storm-resilient housing: Lessons from
Fiji’s Cyclone Winston experience- Draft

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Abstract

Storm-related disasters lead to massive destruction of housing structures all over the world. In 2016, Fiji was struck by Cyclone Winston, which rendered approximately 15\% of the country’s population homeless. In light of the severe devastation brought about by the cyclone, there is a need to better prepare for future hazards, particularly in the resilience of housing structures in developing countries. A research delegation traveled to Fiji and surveyed two villages in Ra province, which were among the most severely affected by the cyclone. The field study was supplemented with an archival review of post-disaster reports and other background information obtained from key government agencies and non-government organizations working on the recovery and rehabilitation of the affected areas. Structural failure modes and patterns on damaged and collapsed houses were observed and analyzed. Results reveal the vulnerabilities of Fijian housing structures to severe winds. Inadequacies are observed in both design and construction aspects, underpinned by people’s awareness of and access to cyclone-proofing practices and technologies, availability of skilled labor, and the corresponding costs. These underpinning factors would have to be addressed in order to develop a storm-resilient housing stock in Fiji.

Keywords: Cyclone Winston; Fiji, post-disaster reconstruction; housing; resilience; storm; building back better

1. Introduction

Severe weather disturbances such as tropical cyclones and hurricanes cause massive destruction leading to extensive economic losses (CRED, 2015; Knabb, Rhome, & Brown, 2005), injuries and loss of lives (CRED & UNISDR, 2015; Munich Re, 2015), and damage to structures (CRED & UNISDR, 2015). Among the structures typically damaged are houses, which may lead to massive displacement of people for a single disaster incident (Boughton et al., 2011; Ginger, Henderson, Leitch, & Boughton, 2007; National Disaster Management Office, 2016; Prevatt, 1994). Recent times have also seen an increasing trend in both frequency and magnitude of
destructive tropical cyclones (Guha-Sapir, Below, & Hoyois, 2015); as such need arises to learn from previous disasters in order to better prepare for the onset of much bigger hazards.

In February 2016, the island nation of Fiji was severely struck by Cyclone Winston. The cyclone commenced as a tropical disturbance but developed into a Category 5 cyclone, based on the Australian tropical cyclone scale, prior to entering Fiji (National Disaster Management Office, 2016). As it approached Fiji’s largest and most populated island, Viti Levu, the cyclone peaked in its intensity packing winds with a 10-minute sustained speed of 230 kph (64 m/s) and gusts peaking at 325 kph (90 m/s). The cyclone destroyed 9,173 houses, significantly damaged 16,757 houses, partially damaged 29,000 others, and rendered approximately 131,000 Fijians, which is about 15% of the country’s population, homeless (National Disaster Management Office, 2016).

Cyclone Winston is, by far, the most intense cyclone to ever impact the island nation of Fiji on record (Diamond, 2017). Fiji has never experienced a Category 5 cyclone before it. The most recent destructive tropical cyclone that affected the island nation before Cyclone Winston was Cyclone Evan in December 2012, a Category 4 on the Australian Scale (Bureau of Meteorology - Australia, 2017). Prior to these two events, the strongest cyclone to have made landfall in Fiji was Cyclone Nigel in 1985, which was a Category 3 on the Australian scale. Recent years have seen an increasing trend in storm intensities over the South Pacific basin (Kossin, Olander, & Knapp, 2013). A study by Holland and Bruyere (2014) reveals that the global shift towards stronger (Category 4 and 5) cyclones and hurricanes is brought about by increasing global surface temperatures due to anthropogenic climate change. There is also a corresponding increasing trend in the annual cost of storm disaster damage in the Southern Pacific (Guha-Sapir et al., 2015).

In view of the rehabilitation and recovery efforts taking place, it is important to consider the principle of building back better or building back safer, which is among the primary foci of most existing disaster recovery frameworks: the most notable being the Sendai Framework for Disaster Risk Reduction (SFDRR) (UNISDR, 2015). SFDRR emphasizes the rebuilding of structures, systems and communities to a higher standard; in other words, stronger, safer, and more resilient than what existed before a hazard struck.

One of the facets of building back better is the development of a resilient post-disaster building stock (Mannakkara, 2014), i.e. buildings are reconstructed to a higher structural performance compared to those that existed before the disaster event. In order to achieve this, we must fully understand building performance when exposed to a particular hazard. At the outset of every disaster, there is a plethora of information useful for this purpose; which is why, it is essential to carefully record and analyze data during post-disaster assessments (Harrison, Silver, & Doberstein, 2015; Stewart, 2003). Systematic post-disaster reconnaissance surveys and building damage assessments capture data necessary for the identification of building behavior, structural vulnerabilities, and failure mechanisms. Much work has already been done in this area in the general sense, (Agarwal, 2007; Li, Ahuja, & Padgett, 2012; Mannakkara & Wilkinson, 2013; Merritt et al., 2001), and on addressing structural vulnerabilities, (Prevatt, 1994; Rosowsky, D. & Schiff, 2003; Shelter Cluster, 2014). It is, however, pertinent to consider nuances in structural design and in construction materials and methodologies, which could be regional in scale or very area-specific, which then could strongly influence structural performances. This highlights the importance of area-specific studies, to complement generalized studies.

Another integral aspect towards developing a resilient building stock is ensuring compliance with building standards and regulations (Hofmann, 2014; Mannakkara & Wilkinson, 2013; Rosowsky, David V., 2011). Among
the typical challenges, however, are the steep costs associated with making buildings code-compliant (Anderson, 2000; McEntire, 2011; Rosowsky, 2011), as well as the lack in knowledge and skills among owners and builders (Prevatt, 1994; Rahmayati, 2016; Stewart, Rosowsky, & Huang, 2003).

In light of the increasing intensity and the corresponding damages brought about by hazard events, one of the strategies by which building stock resilience is achieved is by institutionalizing building codes or by upgrading existing building standards (Mannakkara & Wilkinson, 2013; Moullier, 2015). As such, it is common for a country to revisit their building regulations after a disaster. For example, Hurricane Gilbert elicited the mandatory implementation of the Jamaican Building Code (Prevatt, 1994). According to Boughton et al. (2011), Cyclone Yasi prompted the review and revision of AS 4055: Wind Loads for Housing (Standards Australia, 2012c), AS/NZS 1170.2: Structural Design Actions – Wind Actions (Standards Australia, 2016), AS/NZS 4505: Garage doors and other large access doors (Standards Australia, 2012b), and AS/NZS 2050: Installation of Roof Tiles (Standards Australia, 2012a). In the Philippines, cyclone Haiyan in 2013 elicited changes in the country’s design wind speed zoning (Association of Structural Engineers of the Philippines, 2015; De Leoz, Kaw, Quidilla, Valbuena, & Garciano, 2014). Again, this strategy should be balanced against cost and the population’s ability to comply.

This paper examines Fiji’s Cyclone Winston experience in view of the resilience of housing structures. Specifically, the research aims to evaluate design and construction vulnerabilities, as evidenced by damages caused by the cyclone, and identify other non-structural factors affecting the resilience of housing structures to storms. Such information is pertinent to build back better and establish resilient Fijian settlements. This research contributes to the narrow body of literature concerning severe wind resilience of housing structures in Fiji and the South Pacific. It may also serve as a template for future localized research in relation to the storm resilience of structures.

2. Methodology

2.1. Research Methods

A field study was conducted between the 5-19 June 2016 by a delegation of six researchers from Victoria University of Wellington and the University of Auckland and two personnel from the Fijian National Red Cross.

Ground data were collected from field visits to two villages. The villages were selected based on their proximity to where the cyclone has made its landfall in order to capture the damage brought about by a Category 5 cyclone at its peak. In order to isolate the effect of Cyclone Winston, the selection was limited to villages that have not experienced a recent destructive disaster or have fully reconstructed from their most recent disaster experience prior to Cyclone Winston. The village selection was done in coordination with the Fijian Red Cross Society Office in Rakiraki, which had been working with several villages near the ground-zero of the tropical cyclone destruction.

Structural damage assessment was conducted for houses in these two villages. Houses in the two villages were classified based on structural design and prevalent construction material. For each of the identified housing classes, damages brought about by the cyclone were observed primarily on wind-sensitive components such as structural framing, roof and roof framing, walls and windows. This study involves three of the housing damage assessment tools identified by Jha et al (2010). These are:
1. Reconnaissance walk: A rapid visual assessment of the post-disaster state of the community was conducted. This provided an insight on the building stock present in the area and an overview of the range of the extent of damages.

2. Photographic documentation: Housing damage was documented at the household level by means of photographs. Additionally, a drone mounted with a camera was flown to capture aerial videos of both villages. The videos were used to evaluate the extent of damage to housing and other structures in the villages. Drones have previously been utilized for disaster mapping and damage assessment in the aftermath of Cyclone Haiyan in the Philippines in 2013 and Cyclone Pam in Vanuatu in 2015 (FSD, 2016).

3. Habitat mapping: The extent of damage on the houses was analyzed in relation to their geographical location, structural properties, and other pertinent factors.

Interviews were conducted to capture first-hand experiences of homeowners on the performance of their houses during the tropical cyclone and to determine post-disaster actions carried out from the outset of the disaster to the time prior to the field visit. This enables the integration of information that could not be observed anymore at the time of the field visit such as damages that were already repaired and failure modes of houses that were destroyed. Necessary human ethics approval was secured for the interviews. With due permission from the village headman, stratified random sampling was conducted with homeowners based on their status of housing reconstruction at the time of visit. Three respondents were selected from each category as follows:

1. Not started reconstruction and were still living in tents
2. Built makeshift houses using materials recovered after the cyclone.
3. Partially completed reconstruction of a formal house
4. Completed reconstruction

The respondents were asked the following questions, as applicable:

1. What damages did your house sustain from the cyclone? Were there parts that almost failed?
2. How did the damage progress? Which parts were damaged first? Which parts were damaged last?
3. Did you employ strengthening measures to your house while the cyclone was ongoing? What were those?
4. Did you perform repairs to your house after the cyclone? What repairs did you do to your house after the disaster?

The modes by which structural failures occurred were inferred based on two things (1) empirical observations and (2) comparison with failure modes of similar structures found in the literature.

An archival review of post-Winston records was carried out to provide background data and context. These documents were secured from relevant agencies and organizations including the Shelter Cluster, National Disaster Management Office, Ministry of Industry, Trade and Tourism, Bureau of Statistics, and the Fiji Institution of Engineers.

2.2. Study Area and Location

The villages of Nokonoko and Nabotolu are located in Ra province on the northeastern part of Viti Levu, Fiji’s main island. The province of Ra has 89 villages spanning a total area of 1,340 square kilometers. It has a
Population of 30,432, 80% of which are living in rural areas. At 56%, the province also has the highest poverty incidence in all of Fiji’s 14 provinces (World Bank, 2011). In terms of damage to housing structures, Ra was the most severely affected by Cyclone Winston (Esler, 2016). 46% of houses were completely destroyed and 21% were left partly damaged. Ra was also one of the provinces most severely affected by Cyclone Evan in 2012 (SPC-SOPAC, 2013).

Both villages are iTaukei villages by ethnic composition. These villages are led by a village headman, called turaga ni koro. Unlike their Indo-Fijian counterparts that are generally highly individualistic (de Vries, 2002), iTaukei is a collectivist society (Belshaw, 2013). The strong community ties also translate to strong risk-sharing arrangements and better collective memory of disasters (Brown, Daigneault, Tjernström, & Zou, 2018). The iTaukei, or indigenous Fijians, comprise 56.8% while Indo-Fijians comprise 37.5% of Fiji’s population.

Both villages are situated where Cyclone Winston made its landfall as it struck Fiji’s main island and are among the most heavily affected by the cyclone (National Disaster Management Office, 2016). Figure 1 shows the approximate location of the study area vis-à-vis the track of the tropical cyclone.

Both villages have not had a major disaster experience in recent years. The last disaster that caused damage to housing structures in the area was Cyclone Evan in 2012. The houses damaged post-Evan had since been restored. While the distribution of housing in these two villages are not representative of the entire province of Ra because both were situated in rural areas, the three major housing types, which comprise 97% of the Fijian housing population, are present in the study areas.

Figure 2 shows the specific location and terrain of the two villages selected as study area. Nokonoko is situated approximately 1.5 km from Viti Levu bay coast, on the foothills approaching the mountains that trace Viti Levu’s northeastern coast. Nabouleolu is closer to the bay at around 800 m from the coast and lies on flat terrain. Both villages are accessible by dirt roads, approximately a kilometer in length from Kings Road. Kings Road, along
with Queens Road, forms Viti Levu’s main circumferential thoroughfare that connects the villages to major centers such as Suva, Fiji’s capital, and Nadi where the country’s international airport is situated.

Figure 2. Close up map showing the location and terrain of the two villages (Source: Google Earth)

Housing is the primary post-disaster concern of the people in the study area. In a quality of life (QoL) survey conducted by Potangaroa (2016) in Nokonoko, 43% of the village residents selected housing as the key issue they are faced with. The same study reports that the typical per household income is below 5,000 FJD (2,500 USD) and that 5.9 is the average family size.

3. Results and Discussion

3.1. Damage scoping through aerial photography

Forty-two out of forty-three houses in Naboutolu village were destroyed when Cyclone Winston struck. At the time of the damage survey, four months after the cyclone struck the area, the village was still far from full recovery as can be observed in the aerial view of the village shown in Figure 3. Village residents still lived in temporary dwellings, in tents provided by non-government organizations (NGOs), in makeshift houses built from corrugated iron sheets and scrap wooden plies and panels, materials that previously had formed the roofs or walls of houses damaged by the storm, or a combination of both. Remnants of houses totally destroyed with only the floor and subfloor structures left are also observed, such as that marked 1 on Figure 3: a house that was constructed three months prior to the cyclone but was left with only the elevated floor structure after the cyclone took its course. Structures marked 2 on Figure 3 were left without roofs after the cyclone and were still unrepaired at the time of the survey.
The post-disaster condition in the village of Nokonoko shows a more advanced state of recovery than that in Naboutolu at the time of the survey as can be observed in Figure 4. Although power supply was yet to be restored, approximately half of the houses left roofless by the cyclone had their roofs replaced with new corrugated iron sheets. Around 30% more are being repaired at the time of the survey. The rest were left either unrepaired or had been remedied with temporary measures such as tarpaulin or tent material cover. Approximately 60% of the houses in the village were left without roofs after the cyclone. Of the 96 households in the village, only three families remain settled in tent houses. The unrepaired structures cover a range of damage states from minor roof removal to total demolition with only the floor and/or subfloor system left of the house. These structures show evidence of the various failure modes the houses succumbed to during the cyclone.
3.2. Structural damage to various building types

Caimi (2016) classifies local Fijian housing into three types: traditional, transitional, and formal housing as shown in Figure 5. Traditional houses, contemporarily called bure, are wood-framed houses with thatch roofs and matted bamboo or reed for walls. Transitional houses are typically timber-framed houses with either wooden mats or wood panels or corrugated iron walls. These houses are typically the residence of lower-income families until they can afford to build formal houses. Formal houses are typically of concrete construction, with concrete hollow block (CHB) walls and timber or steel roof framing.

Figure 6 shows the composition of the Fijian housing stock by type of construction (Esler, 2016). Figure 6a shows the distribution among the identified construction types for the entire country while Figure 6b shows the percentages for Fiji’s Western Division, which includes the Ra province, to which both villages studied in this research belongs. Timber houses, consisting of timber-framed ones with corrugated iron envelope and houses that are made of wooden panels, comprise the majority of houses, 57% nationwide and 53% in the Western Division. These structures are analogous to what Caimi (2016) identified as transitional housing. Comprising around 40% of the housing stock are concrete houses, which could be construed as formal housing. Bures and makeshift houses comprise 2% and 1%, respectively.

Houses in Naboutolu were all timber, either with corrugated iron sheet envelope or with timber panel walls. In Nokonoko, the split between timber and concrete structures was approximately 70:30. There were no inhabited traditional houses in both villages surveyed. The proportion of transitional timber housing in the two study areas are higher than the average for Fiji’s Western Division because of the rural nature of the villages. All houses in the two villages are single-story structures, with a typical floor area of 24 square meters, although it ranges from 12 square meters to more than 100 square meters in the villages surveyed.
For the purpose of this study, housing structures are classified according to structural system and material. Based on the preliminary rapid structural survey, there are differences in the damage sustained by on-ground houses to damage to houses with elevated flooring. As such, houses in the two study areas could be associated into three types: (1) concrete, (2) timber with on-ground flooring, which includes houses on plinth, and (3) timber with raised flooring.

The first type has concrete framing, concrete hollow block (CHB) walls, timber roof truss and corrugated iron sheets for the roof sheathing. This type is analogous to the C1-L structural type under the US-HAZUS-MH classification in the US (FEMA, 2010). A typical roof for this type of structure consists of 0.37mm thick corrugated iron sheets fixed by roof nails every other ridge to pine timber trusses. These thin corrugated iron sheets have now been replaced by 0.42mm or 0.55mm sheets for roofs that were repaired and replaced after Cyclone Winston.

Figure 7. Removal of roof sheathing due to shearing of the galvanized iron material. Source: field survey

Many of these structures had their roof sheathing removed during the storm but the walls remained intact. The removal of roofs was predominantly initiated by the shearing of sheets as can be observed in Figure 7. Same damage was observed on similar structures after Cyclone Larry (Ginger et al., 2007) and Cyclone Yasi (Boughton et al., 2011) struck Australia in 2006 and 2011, respectively. Rusting of roof nails creeping onto the sheathing was also observed in roof debris as shown in Figure 8. This contributed to the detachment of the corrugated iron sheets from the purlins by means of pull-through failure, that is, pulling off of the corrugated iron sheets on the rusted portions.
Figure 8. Rusting of the roof nails also corroded the old corrugated iron sheets. Source: field survey

The second and third types can be associated with the W1-L (low-rise, wooden structure) in the HAZUS-MH classification scheme (FEMA, 2010). Based on a matrix of product listings (as of June 2016) of the four biggest construction material suppliers in the country, and the materials list released by the Help for Homes Initiative, it was found out that timber in Fiji is predominantly either sourced locally or imported from New Zealand.

The second type used timber panels walls, usually pine, with on-ground flooring or built over a plinth confined by concrete hollow blocks. These houses had 0.37mm thick corrugated iron sheets for roofing. None of these houses in Nabotolu were left standing after the storm. Only traces of the floor/plinth remained. The observed remnants of the houses suggest the absence of a framing structure and a reliable anchorage to the ground through foundations. These structures failed due to an inadequate framing system that would resist the pressures caused by the intense winds of the cyclone (Agarwal, 2007; Merritt et al., 2001). Specifically, in the absence of a proper frame, the structure fully depended on the stiffness of the timber boards comprising the walls to resist positive pressures. External suction pressure, as well as the buildup of positive internal pressure, on the other hand, was solely resisted by connectors holding the walls and the roof together. Caimi (2016) documented the prevalence of the sparse use of short nails in connecting various parts, e.g. wall-to-wall and wall-to-roof, for low-income houses in Fiji. Uprooting, sliding and or overturning of the entire house structure was resisted by the embedment of the walls and supplemental timber frame, if any, to the ground or the anchorage to the plinth through embedded nails. These connectors proved to be insufficient in spacing and length as demonstrated by their performance against Cyclone Winston. Total collapse of non-engineered and unframed, or inadequately framed, wooden housing structures has also previously been observed after Hurricane Gilbert passed through the Caribbean nations (Prevatt, 1994).

The third type is also of wooden construction but with elevated floors. The floors are typically elevated by approximately 0.4 to 0.5 meter supported by 150mm-diameter pine posts. The floors are elevated secure the floor against floods and to prevent the timber planks from decaying quickly from the frequent wet-dry cycles. It also provides passive cooling for the house during hot days. Houses of this type used prefabricated pine timber panels for the walls. The houses also had corrugated iron sheets attached to pine timber rafters with nails every other ridge for the roofing. Based on the account of village residents, all three houses in Nabotolu of this construction type were among the first to be destroyed at the onset of the cyclone.

The substructure of these houses remained relatively intact whereas everything from the walls up to the roof was demolished as shown in Figure 9. This type of failure was also observed in the aftermath of Hurricane Alicia in the Houston-Galveston area in 1983 (Kareem, 1985). Observing the remnants of these structures, it can be inferred that this type was vulnerable at the connection between the superstructure (the portion of the structure above the
floor) and the substructure (the structure from the floor down to the foundation). Hence, instead of the load being transferred onto the foundation, the superstructure was detached from the substructure as the tropical cyclone exerted pressure on the house. This inference is supported by the accounts of three village residents who were interviewed.

A closer inspection reveals that only the floor beams were directly connected to the foundation. The walls were connected by straps onto the floor beams, the remnants of which can be seen in Figure 10. The spacing, however, is approximately 2 meters, giving each strap a tributary area of 6 square meters, which is sparse and subpar to the code considering that it is what mainly connects and transfers load from the superstructure to the substructure.
The wall panels are additionally connected to the floor beams and floor joists using jolt head nails spaced at approximately 150 mm as shown in Figure 11. This proved to be insufficient as the nails were pulled out with the walls during the cyclone.

Figure 11 also shows damage on the flooring of these houses, where approximately a tenth of the floor planks had been removed. This could have contributed to the build-up of internal pressure that led to the destruction of the structure. The effect of pressure build-up leading to structural collapse is documented in the study by Li et al. (2012). The combined negative external pressure and positive internal pressure resulted in greater loads on the walls and the roof, causing the pull-out of nails (Figure 11) and tearing out of straps (Figure 10) that connected the walls to the substructure.

![Figure 11. Details of substructure-superstructure connection in wooden houses with elevated floors. It also shows that portions of the floor planks were removed during the cyclone. Source: Field survey](image)

For all three types, broken windows were a common sight. Despite it being non-structural damage in nature, window breakage or any unintended openings during a storm could have caused an internal wind pressure buildup similar to the effect of removal of floor planks.

One documented damage was due to wind-borne debris. Based on the account of one respondent in Nokonoko village, one of the unframed timber houses, approximately 24 square meters in size, collapsed when a wind-borne corrugated iron sheet impacted on it at a high speed. No structural damage due to falling trees was observed in the study area during Cyclone Winston.

### 3.3. Structural strengthening recommendations

Based on the field observations, one of the means to prevent the removal of roofs is by replacing the old roofs with market-available corrugated iron sheets. The 0.37mm thick sheets that have been used in the older housing stock have already been phased out in the market and replaced with 0.42mm and 0.55mm.

As rusting around the connectors also contributed to the vulnerability of roofs to severe winds, there is a need to consider proper rust-proofing and regular roof maintenance.
The correct selection of building envelope fasteners, i.e. using screws instead of nails, and the appropriate spacing thereof can enable the development of more resilient housing structures. Houses with timber framing built in Koroipita (Peter’s Village) in Lautoka proved to be resilient to the severe winds brought about by Cyclone Winston (Fox, 2016). None of the 230 houses sustained considerable damage despite the fact that houses in adjoining villages with similar topographic conditions were either destroyed or sustained severe damages. The housing structure, developed by Peter Drysdale, used roofing screws instead of nails, 1000 pieces of them, along with 14 coils of straps for every house. This is also supported by an empirical study by Bisa (2013), which demonstrated that the pull-out strength of wood screws in roof assemblies is six times higher than that of wood nails.

Furthermore, there are potential inexpensive alternative means to secure the roofs from storm winds. Magee et al. (2016) documented common adaptation methods used in the urban areas of Fiji, Vanuatu, and Tonga to protect roofs from severe winds. These include tying down the roof to the ground and placing heavy objects such as concrete hollow blocks or tires on top of the roof. These practices, however, should be used with caution ensuring that the roof structure can adequately support the heavy top load. In the event of an impending cyclone, these methods could also be applied to hold the roofs down. Based on the account of the villagers, however, they were not able to strengthen their houses before the onset of the storm.

The prevalent window breakage could be addressed by the installation of window shutters. This will, in turn, prevent the escalation of storm damage to the houses arising from build-up of internal pressure in the house.

Timber houses could be made more resilient to tropical cyclones through design improvements. The incorporation of a proper framing that would resist the lateral wind forces would significantly improve the overall resistance of the housing structure to tropical cyclones. Installation of bracings would further strengthen the house against storms.

There is also a need to strengthen the connection between the superstructure and the substructure for timber houses. This could be achieved by providing adequate nails or screws and/or straps, and consequently decreasing the spacing of the connectors transferring the load from the walls and/or columns to the floor beams and onto the foundation.

3.4. Social and economic factors underpinning housing resilience

The massive destruction brought about by Cyclone Winston in 2016 has spurred initiatives, notably from the government side, to upgrade the current Fijian building standards (Prakash, 2016). The basic wind speed for all of Fiji considering limit state design (LRFD) is 70m/s (Fiji Building Standards Committee, 1990), which is the upper limit of gust wind speeds for Category 4 cyclones. Basic wind speed is multiplied with factors that take into account local conditions such as wind direction, terrain, shielding, and topography, in order to calculate the design wind speed. Cyclone Winston, a Category 5 cyclone, brought winds having a maximum 3-second gust speeds of 82.7m/s upon landfall on the northeastern coast of Viti Levu (National Disaster Management Office, 2016).

The National Building Code of Fiji Islands, which was launched in 1990, was crafted as a response to Cyclone Tusi, a Category 3 system that affected Fiji’s neighboring Pacific Island nations in 1987 (Fiji Building Standards Committee, 1990). The code was instituted as an insurance requirement rather than as a building construction permit requirement and was not intended to be applied for houses and other structures in rural areas. As such,
code compliance is limited to formally constructed buildings in urban areas securing insurance. These structures are mostly commercial and industrial.

State-owned buildings such as schools also need to be retrofitted in order to be code-compliant (Radio New Zealand, 2016). Records from the Adopt a School Program (Mohammed & Singh, 2017) show that it entails tens of thousands up to more than a million Fijian dollars per school to make the school buildings resilient against Category 4 cyclones. From this, it can be perused that cost is one of the crucial factors in making Fijian buildings storm-resilient.

One of the main steps towards improving the Fijian housing stock is through ensuring code-compliance not only for commercial and industrial buildings, but also for housing structures; to mainstream the building code beyond the confines of urban areas (Aquino, Wilkinson, Raftery, Potangaroa, & Chang-Richards, 2018).

Further, whereas a code upgrade is anticipated to improve the building stock, it has to be backed a sound legal framework that elicits regulatory capture (Mannakkara & Wilkinson, 2013; Moullier, 2015). Currently, there is a severe lack of engineers in Fiji who can certify for code-compliance (Aquino et al., 2018) and as of 2016, there are only 18 registered by the Fiji Institution of Engineers (Fiji Institution of Engineers, 2016). This approximately translates to a ratio of one engineer for every 10,000 households in Fiji.

Another challenge to the effectiveness of building code upgrades in developing resilience is its implementability at the level of the community. Key considerations are the financial and technical capability on the part of builders and house owners. For instance, post-Victorian bushfire fire code upgrades led to hefty increase in building construction costs in Victoria, Australia (Mannakkara, Wilkinson, & Potangaroa, 2014). For the increase in the design wind speed in the Philippines, a preliminary case study shows that the corresponding cost increase is about 80% of the minimum monthly salary in the most affected area (Aquino, Wilkinson, Raftery, Chang, & Potangaroa, 2016). While changes in the building regulations enacted after Cyclone Tracy led to more resilient houses (Schofield, Arthur, & Cechet, 2010), the same brought about the proliferation of informal settlements in Jamaica after Hurricane Gilbert (Prevatt, 1994). Tuts (1996) highlights the importance of cost-modeling prior to enacting new building standards to ensure that it is not prohibitive. Benefit-cost analysis is a useful tool to investigate the economic soundness of upgrading to higher building standards. The method has been demonstrated by Peterson and Small (2012) for various levels of seismic code upgrades in Haiti and Puerto Rico, by Simmons et al (2015) for the enhanced building code in Moore City, Oklahoma, and by Simmons et al (2018) in the adoption of a statewide building code for Florida.

In regard to the technical capability, it is essential to ensure that communities and stakeholders are well-informed of the changes (Mannakkara et al., 2014). Communities should also have access to the technical expertise necessary to comply with the code. In Fiji’s case, most communities rely on builders who learned their trades informally as passed on through generations (Aquino et al., 2018). Due to the high post-disaster demand for construction labor, many people do urgent repairs without seeking assistance from skilled constructors. It is, therefore, necessary to upskill village-based builders through capacity-building programs.
4. Conclusion

Overall, Cyclone Winston has brought extensive damage on housing structures in Fiji. The removal of the roof sheathing was a common sight for houses with concrete walls. This could be addressed by using a thicker gaged sheet for the roof sheathing, rust-proofing and maintenance procedures, or the use of screws instead of nails for the connections. For timber houses, their designs could be improved by incorporating an adequate lateral force resisting system that would resist the wind force and an improved superstructure-substructure connection that would effectively transfer the load onto the foundations. The installation of window shutters would also aid in storm-proofing the house.

While there is an imminent review intended for the upgrading of the Building Code of Fiji, the more fundamental problem lies in the coverage and implementation of the existing code. At present, only a limited number of structures are code-compliant: the ones that needed certification of compliance with the building code as a requisite for insurance, mostly commercial or industrial buildings in urban areas. In order to address this, firstly, the code needs to be widely adopted and the information and details that are presented in it need to be disseminated to the common people, particularly village builders. The village builders should be trained for sound construction methods and techniques. Additionally, in line with the goal of building back better, compliance to the code should be considered in the repair or rebuilding of cyclone-damaged houses. The government should consider this in calculating the aid amount that they give to homeowners affected by Cyclone Winston. Secondly, government agencies and related institutions must undergo capacity-building training schemes that would enable them to inspect and analyze for building code compliance.

The findings and learnings incorporated herein, while derived from Fiji’s experience, are not exclusively applicable to Fiji. These learnings are also transferable to other island nations in the Southwest Pacific, which are very similar to Fiji having developing economies and consisting of small islands spread over a vast geographical area (Magee et al., 2016). Among these nations, Vanuatu and Tonga, ranked first and third among the countries most at risk to natural hazards (Birkmann et al., 2014). The study provides insights on how to develop a hurricane-resilient housing stock after a devastating cyclone. This research contributes to the body of knowledge documenting empirical information on wind damages on housing structures. It also provides insights on issues surrounding building code implementation and compliance.

Further studies may be done on the vulnerability of structural types not covered herein. The structural vulnerability derived empirically in this study could also be complemented by structural models.

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7. References


53. Shelter Cluster. (2014). 8 build back safer key messages. Philippines:


57. Standards Australia. (2012b). AS/NZS 4505:2012: Garage doors and other large access doors. Sydney, Australia:


