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# Characterizing Post-Disaster Shelter Design and Material Selections: Lessons from Typhoon Yolanda in the Philippines

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## ABSTRACT

Following a disaster, communities, governments, and organizations are required to make rapid decisions that will govern the path towards long-term recovery. Hazard-resistant shelter designs have long been heralded as necessary for facilitating resilient and sustainable reconstruction; however, there is sparse documentation of designs implemented. We examine the case of design and building material selection for 20 shelter projects following Typhoon Yolanda in the Philippines, using photo documentation, interview data and field observations as a means to document rates of design adoption and choices in material selection. Findings use the shelter cluster '8 Key Messages' as a framework to assess level of improved shelter design. Results highlight improved foundations, roofing, building shape and site selection and identify deficits in structural elements, including connections, bracing, and joints. Findings quantify design features that saw poor uptake by organizations and hold potential to inform future practice that encourages hazard-resistant design in the Philippines and other future international disaster responses.

## INTRODUCTION

While evidence supports a reduction of causalities following disasters, the number of people impacted, the cost of damages and number of annual occurrences of hazard events is steadily rising (EM-DAT 2014). With the adoption of the new Sendai Framework for Disaster Risk Reduction in March 2015, the global community took a significant step towards enhancing resilience at the local and national levels by providing direction that guides policy for disaster risk reduction through 2030 (UNISDR 2015). The framework proposes four priorities: (1) understand disaster risk; (2) strengthen disaster risk governance to manage disaster risk; (3) invest in disaster risk reduction for resilience and (4) enhance disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction. The third goal, investing in disaster risk reduction for resilience, proposes several mechanisms including *"To strengthen, as appropriate, disaster-*

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*resilient public and private investments, particularly through structural, non-structural and functional disaster risk prevention and reduction measures in critical facilities, in particular schools and hospitals and* ***physical infrastructures****;* ***building better from the start to withstand hazards through proper design and construction****, including the use of the principles of* ***universal design*** *and the* ***standardization of building materials****; retrofitting and rebuilding; nurturing a culture of maintenance; and taking into account economic, social, structural, technological and environmental impact assessments."* (UNISDR 2015).

Decision processes in shelter reconstruction are at the forefront of mitigating or reinforcing vulnerabilities of populations (Ritchie and Tierney 2011). Designing economically and socially viable shelters that are safe is one of the most difficult tasks facing non-governmental organizations (NGOs) (Hayles 2010). Studies have examined post-disaster shelter from a variety of perspectives including engineering (Arlikatti and Andrew 2011), planning (Comerio 2014) and economic impacts (Lyons 2009). While these studies have investigated crucial components of shelter, there remains a gap in understanding progress toward universal, resilient designs and standardized building materials in post-disaster reconstruction.

This paper is part of a larger study that is examining the role of coordination, stakeholder participation and training in recovery and reconstruction programs (Opdyke and Javernick-Will 2014). In this paper, we focus specifically on two decision-making outcomes, shelter design elements, and materials, to lay the foundation for future work that will explore coordination processes in non-governmental recovery programs. Towards this goal we ask the following question:

*RQ: What hazard-resistant design elements and materials do organizations select in post-disaster shelter reconstruction?*

This paper will take the first steps towards addressing literature gaps in post-disaster design decision-making by characterizing what design elements and materials are selected in post-disaster shelters.

## METHODOLOGY

We examined reconstruction following Typhoon Yolanda (Haiyan) that struck the Philippines in November of 2013, employing case study methodology (Yin 2009) to document and examine post-disaster decision-making. Yolanda, the strongest typhoon ever recorded to make landfall, devastated the central Philippine provinces and affected more than 12 million people (Masters 2013). Over 1.1 million homes were damaged or destroyed, and the economic impacts were estimated at over $12.9 billion USD (NEDA 2013).

Following initial discussions with agencies on the ground after Typhoon Yolanda, twenty shelter reconstruction projects at the barangay (community) level were selected for comparison. We deliberately sought to obtain differences in organizational strategies and similarities in physical and socio-cultural factors of communities that represented the range of approaches employed. These projects ranged in size from 40 to 365 shelters and community sizes varied from 677 to 4,645.

### Data Collection

An initial field visit was completed in May of 2014 during which the twenty selected projects were identified, and initial interviews with 32 shelter stakeholders were completed. During a second, three-month field visit in January 2015, each of the twenty considered projects were photographed extensively. These photos documented structural components such as bracing, foundation, roofing and other design features of structures. Additionally, 167 interviews with homeowners, government officials, and NGO staff were completed. Interview questions focused on how design and material decisions were made such as *"Can you describe the shelter design process?"* and *"What hazard-resistant aspects were incorporated?"* Further, documentation on shelter design guidance was collected from United Nations agencies and NGOs.

### Analysis

Early in recovery efforts, the shelter cluster generated '8 Key Messages' of shelter designs based on experience of represented organizations. The shelter cluster is one of eleven coordinating bodies deployed under the United Nations Office for Coordination of Humanitarian Affairs (UNOCHA). These simplified design elements were widely distributed under the cluster to organizations, government agencies, and communities. As such, these messages represent an excellent means to evaluate inclusion of accepted better building practices. Each key message and recommended components were extracted from cluster documentation. Design elements for projects were then classified using photo documentation, interviews, and field notes. The last key message, preparedness, was excluded as it did not directly involve engineered designs of shelters.

## FINDINGS

Following analysis of field notes and photo documentation, relative frequencies of design elements for the examined twenty shelter projects were compiled. Findings are reported in four main sections below for designs: (1) foundations; (2) frame elements (tie-downs and connections, bracing and joints); (3) roofing design and structure shape and (4) site location. While there is likely overlap between how these categories are defined, we use this structure as this is how cluster guidance was presented to organizations. We then present a summary of types of materials that were used in shelter reconstruction for structural elements, walls, and roofing. Results are reported using shelter projects embedded within communities as the unit of analysis. All findings are reported as relative frequencies of the twenty projects studied.

### Foundations

Before Yolanda, a significant number of structures lacked adequate foundations. As a result, reconstruction efforts marketed better foundations, namely the use of concrete footings. The shelter cluster identified three types of foundations in shelter projects: simple timber posts, anchored timber posts, and concrete footings. 80% of projects were observed to use concrete foundations. However, connections to foundations were found to be largely inadequate. 20% of projects were observed to use the pre-disaster practice of buried timber posts (anchored and non-anchored). A summary of foundations for projects can be found in Table 1 below.

**Table 1: Foundations**

| *Key Message* | *Description* | *Relative Frequency* |
|---|---|---|
| Foundation | Timber post | 15% |
| | Timber post with anchors | 5% |
| | Concrete footing | 80% |

*N=20*

## Frame Elements

Tie-downs and improved connections were emphasized as one of the most critical improvements needed for shelter structures. Cluster guidelines for improved tie-downs focused on four areas: foundation tie-downs, floor joist connections, truss-post connections and rafter-purlin connections. 65% of projects used nailed rebar as the primary foundation tie-down; 35% of projects use the recommended metal strapping with bolts or nailing. Nailing was the most common method of connection for floor joists in 55% of projects; 45% of projects used the cluster recommended metal strapping. 25% of projects used bent rebar to connect trusses and posts, 50% used nailing and 25% used metal strapping. Lastly, 65% of projects used timber cleats to connect rafters and purlins. The small additional cost for strapping could have brought those structures that used nailing or bent rebar for truss-post connections up to code requirements. These were widely used because of the availability of coconut lumber. However, interviews with homeowners highlighted that the cleats were prone to splitting and appeared to provide little structural support for purlins.

In addition to connections, improved bracing was considered among the major priorities of cluster guidance. In 85% of projects sway bracing, or bracing between trusses, was provided, however adequate connection of these members was often absent. Single nails were often the only method of connection. In contrast, only 20% of cases used bracing across roof members. 85% of projects also made use of bracing for silts, where applicable. Troublingly, 45% of projects used no lateral bracing for walls. Bracing was commonly designed to act in compression but rarely found sufficient to act in tension. The shelter cluster recommended that bracing stay between 30 and 60 degrees, however only 60% of projects exhibited this guideline. In summary, these numbers highlight a wide variance in structural frame elements. The absence of lateral resistance elements is particularly concerning given the region's high winds and seismic activity.

Lastly, joints were another category analyzed. Due to lacking manufactured connectors, several alternatives were proposed by the shelter cluster to strengthen joints. Examples included extending joints to avoid splitting from nails, notching members, offset and angled nailing, fishplating horizontal members and gusset plates for trusses. Joint extensions saw the lowest inclusion of these methods with only 25% of projects observed. Notching had the highest presence in 95% of the observed cases. 50% of projects used offset nailing and 45% used angled nailing. 80% of projects used nailing, straps, fishplates, or bolts for horizontal joints. Finally, 45% of projects used gusset plates for trusses. Similar to other frame elements, these numbers highlight a division of unified strategy adoption in joint design. A summary of relative frequencies for tie-downs and connections, bracing and joints can be found in Table 2.

**Table 2: Frame Elements**

| *Key Message* | *Sub-Category* | *Description* | *Relative Frequency* |
|---|---|---|---|
| Tie-Downs and Connections | Foundation Tie-Down | Nailed rebar | 65% |
| | | Metal strapping with bolts or nails | 35% |
| | Floor Joists Connection | Nailed | 55% |
| | | Metal strapping | 45% |
| | Truss-Post Connection | Rebar | 25% |
| | | Nailed | 50% |
| | | Metal strapping or bolts | 25% |
| | Rafter-Purlin Connection | Directly nailed | 5% |
| | | Timber cleats | 65% |
| | | Metal strapping or bolts | 30% |
| Bracing | Truss Bracing | No bracing | 15% |
| | | Steel wire or rebar | 5% |
| | | Nailed timber braces | 60% |
| | | Strapped or bolted timber braces | 20% |
| | Roof Bracing | No bracing | 80% |
| | | Steel wire or rebar | 0% |
| | | Nailed timber braces | 10% |
| | | Strapped or bolted timber braces | 10% |
| | Silt Bracing | No bracing | 15% |
| | | Nailed timber | 20% |
| | | Strapped or bolted timber or N/A | 65% |
| | Wall Bracing | No bracing | 45% |
| | | Nailed timber braces | 40% |
| | | Strapped bolted timber braces | 15% |
| | Bracing Angle | $\theta<30$ or $\theta>60$ | 40% |
| | | $30<\theta<60$ | 60% |
| Joints | Joint Extensions | No extensions | 75% |
| | | Extension past post or N/A | 25% |
| | Notching | Notched more than 1/3 | 5% |
| | | Notched less than 1/3 or N/A | 95% |
| | Nailing Offset | Nailing in-line | 50% |
| | | Nailing offset or N/A | 50% |
| | Nailing Angle | Nailing is straight | 55% |
| | | Nailing is at angle, screws or N/A | 45% |
| | Horizontal Joints | No connectors used | 20% |
| | | Nailing | 40% |
| | | Fishplate, straps, bolts or N/A | 40% |
| | Gusset Plates | No gusset plates used | 55% |
| | | Timber or steel gusset plates or N/A | 45% |

*N = 20*

## Roofing Design and Structure Shape

The most obvious damage in many communities following Yolanda was roofing. Thin roof sheeting, nailing, roof angle, and overhangs were pre-disaster design flaws that contributed to damage. Post-disaster strategies identified six areas of improvement: eave length, pitch, edge nailing, overlapping sheets, nailing type and roof shape. 80% of shelter designs adopted shorter eaves, 85% adopted a moderate pitch (between 15 and 50 degrees), 90% used overlapping roof sheets and 95% made use of improved nail types. An increased number of nails for edges was found in 60% of projects. For roof shape, 60% of projects used a gable design, while the remaining 40% selected hipped. These numbers demonstrate a relatively high level of standardization in roofing design.

**Table 3: Roofing Design and Shelter Shape**

| *Key Message* | *Sub-Category* | *Description* | *Relative Frequency* |
|---|---|---|---|
| Roofing | Eaves | Longer than 45cm/1.5ft | 20% |
| | | Shorter than 45cm/1.5ft | 80% |
| | Pitch | θ<15 or θ>50 | 15% |
| | | 15<θ<50 | 85% |
| | Edge Nailing | No additional nailing provided | 40% |
| | | Additional nailing provided or not applicable | 60% |
| | Overlapping Sheets | Sheets do not overlap | 10% |
| | | Sheets overlap or not applicable | 90% |
| | Nailing | Regular nailing | 5% |
| | | Umbrella nail or wire | 60% |
| | | Twisted umbrella nail head or roofing screw | 35% |
| | Shape | Monoslope | 0% |
| | | Gable | 60% |
| | | Hipped ("Quatro Aquas") | 40% |
| Shape | Overhangs | Overhang on at least one wall face | 0% |
| | | No overhangs | 100% |
| | Layout | Irregular shape | 10% |
| | | Rectangular or square shape | 90% |
| | Length | Building at least twice as long as wide | 0% |
| | | Building does not have side more than twice width | 100% |
| | Awnings | Awnings attached to main roof | 20% |
| | | Awnings separate from main roof | 80% |
| | Building Groups | Housing groups trap wind | 5% |
| | | Housing groups allow for adequate wind flow | 95% |

*N=20*

The last engineered feature analyzed was shelter shape. This included wall overhangs from a second story, layout (e.g. regular vs. irregular shape), length relative to width of structure, attachment of awnings and clusters of buildings. None of the observed projects built second story overhangs in new construction. 90% of projects kept to simple, regular shapes. Similarly, none of the shelters designed were more than twice as long as wide. 80% of shelters attached awnings separately; the other 20% integrated these into roof members. Lastly, 95% of cases exhibited planning that allowed for wind paths between structures. These findings demonstrate that shelters largely consisted of simple shapes, avoiding additional design complexities. A summary of roofing design and shelter shape considerations can be found in Table 3.

## Site Selection

In addition to engineered components, another design feature highlighted by cluster guidance was site selection. This is obviously an important consideration as this determines the impact of hazards on shelters. Hazards considered included flooding/storm surge, rockfall/slopes, debris, and wind. None of the projects observed had a high risk of rockfall or landslides. 10% of cases were found to have increased wind exposure due to their position along unprotected coastal areas. The two highest levels of exposure, flooding/storm surge and debris (e.g. falling trees), were found to be present in 20% of projects. The first reaction for many organizations was to remove the risk of hazards through location rather than designing to meet hazards. This is obvious by the relatively low levels of exposure. In certain cases, such as several of the urban projects, these hazards were unavoidable, however. A summary of site selection and hazards exposure can be found in Table 4.

**Table 4: Site Selection**

| *Key Message* | *Sub-Category* | *Description* | *Relative Frequency* |
|---|---|---|---|
| Site | Flooding or Storm Surge | Floor not raised and prone to flooding/storm surge | 20% |
| | | Silted house or not applicable | 80% |
| | Rockfall or Slopes | Prone to landslides or rockfall | 0% |
| | | Safe distance from landslides or rockfall or N/A | 100% |
| | Debris | Within distance of falling trees or other debris | 20% |
| | | Safe distance from falling debris or not applicable | 80% |
| | Wind | Exposed to coastal winds or high on mountain | 10% |
| | | Inland or protected from winds | 90% |

*N=20*

## Building Materials

In the wake of Typhoon Yolanda, construction material supply chains were overwhelmed by reconstruction needs. Sourcing materials in any disaster environment is difficult as suppliers dramatically increase prices and material stocks are depleted from overwhelming demand. Yolanda was no different, and accessing usable materials that were of suitable quality became a priority for organizations during the first year of recovery. The most common material alternatives considered by housing stakeholders for structural elements included (1) coconut lumber; (2) hardwood lumber; (3) concrete masonry units; and (4) reinforced concrete.

The typhoon downed nearly 33 million coconut trees – one of the key resources, and industries, of the Philippines (UNDP 2014). As a result, coconut lumber became the most readily available option for many stakeholders as downed trees had to merely be cut on site. Trying to turn loss into opportunity, many organizations turned to this as a locally sourced building material that could stimulate economic recovery through reconstruction efforts. While coconut lumber was widely used in the Philippines before Yolanda, dialogue following the disaster raised concerns about the material's durability and structural strength. The expected lifespan of untreated coconut is estimated to be between three and five years, the wet climate and termites to blame for degradation.

In addition to coconut lumber, hardwood lumber was another alternative that could be imported from other geographic regions. Due to strict deforestation legislation within the Philippines, lumber was imported from neighboring provinces or nearby countries such as Malaysia. Hardwood species did, however, afford greater durability with lifespans expected to be over 25 years and more amiable structural properties. Costs, however, were on average more than ten times that of coconut lumber. Concrete masonry units were another alternative used in housing reconstruction, and production of such blocks was widely available across affected regions. The quality control of blocks was poor however and mix ratios were inadequate. Mixes commonly used beach sand that was not washed, raising concerns on long-term corrosion of reinforcement. Reinforced concrete was a final alternative. However, this was largely reserved for industrial construction outside of the housing market, although some organizations did employ this material for select elements. A summary of structural element materials selected can be found in Table 5. Notably, several of the projects employed more than one material, such as was the case for masonry skirt walls with timber framing.

**Table 5: Shelter Materials**

| | *Material* | *Expected Lifespan* | *Relative Frequency** |
|---|---|---|---|
| Structural Elements | Coconut Lumber | 3-5 years | 75% |
| | Hardwood Lumber | Up to 25 years | 15% |
| | Concrete Masonry Unit | >25 years | 35% |
| | Reinforced Concrete | >25 years | 20% |
| Roofing | Nipa (Palm Leaves) | 1-2 years | 10% |
| | Corrugated Galvanized Iron Sheeting | Up to 25 years | 85% |
| | Reinforced Concrete | >25 years | 5% |
| Walls | Amakan (Women Thatch Leaves) | 3-5 years | 30% |
| | Plywood | Up to 10 years | 65% |
| | Concrete Masonry Units | >25 years | 30% |

**Note: Several projects included more than one material.* *N=20*

The second area of material selection involved non-structural elements for housing such as roofing and walling. For roofing, three primary selections were observed: (1) Nipa (traditional palm leaves); (2) corrugated galvanized iron (CGI) sheeting and (3) reinforced concrete. Homeowners reported that Nipa roofing would last from one to three years before replacement was required and minor leaks might occur during that time. From a usability standpoint, Nipa roofing is considered superior for ventilation compared to CGI and initial costs were approximately ten times lower. CGI was prone to corrosion from proximity to the sea, however, typical useable life in these conditions is expected to be over twenty years. Reinforced concrete was the most durable roofing observed. However, it required stronger frame elements not found in most structures.

The third area of material selection involved wall materials consisting of: (1) amakan (woven thatch leaves); (2) plywood and (3) concrete masonry units (CMUs). Amakan again provided the most ventilation, however, required frequent replacement compared to plywood and CMUs. Further, the amakan walling was prone to leaks during rain as pointed out by some homeowners. Plywood resolved problems of weatherproofing and was only slightly more expensive however common thickness was 1/8", resulting in material degradation in short periods if left in contact with moisture. CMUs were a final alternative that saw selective use, primarily in masonry skirt walls with timber framing on top. A summary of building materials applications and relative frequencies in the observed projects is presented in Table 5.

## CONCLUSIONS

In this paper, we have characterized the design and material decisions made by organizations in twenty shelter reconstruction projects following Typhoon Yolanda. We adopted the shelter cluster '8 Key Messages' as a framework to assess inclusion of design elements, using extensive photo documentation, interview data, and field notes to categorize projects. Further, we presented frequencies of material selection for structural elements, roofing, and walls.

Findings demonstrate improved design of shelters in several key areas including foundations, roofing, building shape and site location. Each of these areas made significant improvements compared to pre-disaster construction methods. Despite these advances, there was substantial variance in connections, bracing, and joints. In particular, the lack of lateral bracing in 45% of projects highlights a significant gap in hazard-resistant design adopted by organizations. Additionally, upwards of half of projects examined utilized poor structural connections. Implementing organizations and future shelter cluster leadership should seek to improve knowledge dissemination on the importance of lateral resistance and connections in shelters.

Material selection showed that 75% of projects used coconut lumber for structural members. This has significant implications for long-term sustainability and resilience of projects given its lack of durability and structural properties. Organizations should judiciously consider shelter material alternatives in consultation with local partners. In particular, implementing agencies should cautiously approach equating local materials with cultural preferences or workforce construction skills.

Our results fill a gap in literature surrounding the current state of design adoption in disaster recovery by organizations. In particular, we have quantified design elements that are selected by organizations following one case as a benchmark toward achieving universal, resilient shelter design. Findings provide a useful step in evaluating progress toward successful implementation of the UNISDR Sendai Framework. This research presents a clear framework to evaluate future design adoption in disaster recovery, and our results can be used in future comparative analysis research. Future work should seek to investigate design decisions in different contexts in order to build theory on organizational decision-making in disaster recovery.

In characterizing design and material decisions in shelters following Typhoon Yolanda, we have taken initial steps in analyzing two decision outcomes. Future work will build on this paper by analyzing the wealth of real-time, qualitative data collected to understand how recovery processes were influential in shaping organizational design decisions. Further, we will also examine how stakeholders participated in planning and design processes to better understand how 'scientific' and local knowledge are perceived and enacted by individuals.

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