QUALITATIVE COMPARATIVE ANALYSIS VARIABLE CALIBRATION NOTES

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Conditions

Planning: Coordination

Shelter Sector Involvement

This condition was defined by the degree to which project goals aligned other regional shelter organisations, demonstrated by involvement of the primary project shelter organisation in the Shelter Cluster. Set membership was based on cluster involvement of the primary organisation(s) constructing shelter. In set membership was characterized by organisations that actively participated in the Shelter Cluster. Conversely, organisations which had no involvement constituted out of set membership. Drawing from our case knowledge, cluster involvement was largely seen to correlate with alignment of regional shelter strategy. This was partially due to the exposure provided to alternative approaches as well as access to the collective knowledge of participating organisations.

Cross-Sector Integration

This condition was defined by the degree to which shelter organisations considered complimentary infrastructure and services in planning. While alignment of strategy within sectors is important, cross-sector integration also characterizes another important aspect of coordination [1]. This is substantiated through theoretical definitions [2] but also empirical evidence [3]. Cases show that a number of organisations choose to adopt no integration of sectors and the approach was solely on shelter. In contrast, other organisations chose to either accomplish integration under their own programs or by partnering with external organisations. For this condition, planning that excluded other sectors represents out of set membership while in set membership was defined by inclusion of multi-sectoral planning under the implementing shelter organisation. Three commonly observed sectors of programming were used with equal weight assigned to each. Integration, defined as documented partnership or intention to provide service in a sector, is the sum of provision of each sector during the planning phase.

Land Rights

A growing area of importance in humanitarian shelter projects is the inclusion of housing, land, and property rights (HLP) into early coordination. It broadly encompasses securing tenure and ensuring that populations are awareness of their occupancy rights. As this often involves multiple stakeholders, such as landlords and local governments, it can be considered a vital aspect of early coordination. Cases where land tenure were not secured in planning were defined as out of set, while in set constituted tenure with documentation. Another case, secure tenure but without documentation was added slightly in the set as this did not fully address long term implications of tenure security but did afford a short-term solution.

Planning: Participation

Location Selection

Given that location is a precursor to subsequent decisions in recovery, location selection was included as one of the components that comprise participation during planning. The process of involving homeowners into planning efforts being led by government agencies and NGOs varied greatly and provided for differing levels of participation by communities, however two distinct groups emerged – households that did select location and those where location was decided by a government agency or NGO.

Determination of Aid

The process for determining priorities and participation of stakeholders during planning was governed by the initial determination of aid. Donor requirements that were more open ended and had mechanisms to facilitate community feedback allowed for participation. In contrast, donor funding that was predetermined excluded stakeholders during these early stages. We distinguished between in set

and out of set membership here by whether there was a formal needs assessment conducted within a community prior to distribution of shelter assistance. Further granularity was added by considered whether the assessment was first-hand or second-hand.

Design: Coordination

Provision of WASH

It is critical that design of infrastructure be coordinated across infrastructure sectors. Electrical supply, and for the most part transportation infrastructure, was already in place and operational prior to the construction of other infrastructure assets observed in recovery. Shelter, water supply, and sanitation infrastructure were the most common ground where coordination was required, given the state of other infrastructure. As such, we only examined these three sectors for this condition. Here we consider design to be the technical and operational plans by either the shelter organisation or by another organisations working in the community.

Uniform Design Standards

The presence of uniform design standards was one of the hallmarks of the Shelter Cluster in the response. Their 8 Key Messages provided one method to evaluate whether an organisation's shelter design aligned with other organisations. Out of set membership consisted of lacking adherence to the cluster guidelines, while in set membership consisted of adopting messaging in programming. Documentation distributed to beneficiaries and internally within organisations was the primary means of assessing this adoption.

Design: Participation

Floorplan and Layout

Household participation ranged from no input to individual design consultations. We included large community meetings as the intermediate out of set value due to the nature of these meetings to suppress of the voice of minorities in communities. For in set membership, we distinguish between input on plans that were already completed and open-ended dialogue with homeowners on features. When plans were already developed this frequently led to homeowners withholding opinions due to concern over losing aid support. Overall, out of set membership was distinguished by one-directional communication whereas in set membership was characterized by bi-directional communication between the homeowner and the implementing organisation.

Government Permitting

Another vital element of stakeholder participation during design was the consultation of local government agencies. This was most commonly accomplished through the municipal or city office. In many cases organisations may have approached local governments, but these were often referred to as 'courtesy calls' and lacked real discourse. As a result, we define in set membership as written evidence of acknowledgement by a local municipality or city agency of shelter plans. This often signaled that additional informal feedback was also offered on designs, location, beneficiary selection, and other program details.

Construction: Participation

Sweat Equity

Involvement of beneficiaries in construction labour is one of the primary forms of participation seen in development projects and disaster recovery programs. Here we define in set membership as required contribution of at least some construction labour. Site works, just as clearing and grubbing are considered, but are included as slightly out of the set. We do not distinguish whether the labour was skilled or un-skilled.

Material Procurement

Another task that commonly arose during construction that required beneficiary participation was the procurement of construction materials. This aligns with theoretical notions of participation by means of operational tasks required to implement projects. In set membership was defined by evidence of household involvement in receiving, inspecting, and certifying materials. In some cases, this may have also involved transportation of materials. In contrast, if the organisation acquired all materials this was considered out of set membership.

Financial Management

Separate from procurement, beneficiaries in some cases were asked to manage project finances. This involved being provided a cash sum to manage and control expenses through acquiring labour or materials. This is distinguished from material procurement in that homeowners were in some cases asked to procure materials through established routes, such a designated vendor at pre-established prices, whereas financial management denotes freedom of selection.

Oversight

Past literature [4] has identified both organisational and beneficiary oversight of construction to be an important element of participation. We base the calibration for this condition primarily on the level of action taken in response to construction inspections. Out of set membership was the absence of the homeowner during construction and in set membership was inspections by both the homeowner and organisation at major milestones, such as foundation, wall and roof completion. A third fuzzy value was added slightly out of set for inspections that were conducted but lacked action to correct deficient construction.

Construction: Training

On-Site Observation

While many organisations emphasize the importance of transferring knowledge on safer building principles to homeowners, implementing agencies typically assume that this has to occur through direct and intentional learning activities or materials. In our analysis of construction knowledge across households, we found statistically significant differences in construction knowledge for those households that were present at the construction site. Our interview data from households suggests that in addition to intentional training activates, households acquired new knowledge through observation of new construction techniques applied. As such, we include on-site observations a condition of training. To structure our set, we identified two groups of cases. Out of set membership was defined as lacking presence of the household during construction. This was most common for relocation programs where household did not witness construction and moved after completion of the shelters. In contrast, the ability to observe new techniques being used and ask questions to carpenters and masons defines in set membership.

Diversity of Training Methods

Experiential learning theory (ELT) posits that individuals learn through discovery and experience. Applying this lens to post-disaster training programs, we identified characteristics of formal training programs, mapping these onto the 4 poles used in ELT, including: (a) concrete experience; (b) reflective observation; (c) abstract conceptualization; and (d) active experimentation [see 5]. As each of these stages is important, and collectively they act as a learning cycle, we draw from previous research to suggest that in set membership is defined when training methods touch on all four poles of ELT. Conversely, the absence of training signifies out of set membership. We determined our crossover point by exploring differences in methods and construction knowledge, finding that the combination methods that touches on three ELT poles signified a change in construction knowledge.

Outcomes

Resilience

Overall resilience was taken as the average of infrastructure, governance, economic, and social dimensions. Each sub-condition is weighted evenly within each respective dimension.

Infrastructure

Housing

Housing stock has been shown to be key aspect of community resilience for its role in supporting social and economic recovery [6]. This condition combines shelter design and construction quality to assess housing units within a community. The *minimum* value of sound design principles and quality construction was selected as both have been noted as important in overall contributions of housing to resilience in past literature.

Housing Design

Past studies have relied on contextually bounded indicators of housing resilience (e.g. age of structures) [7]. This is the result of different housing archetypes having inherently different properties in the face of hazards. Drawing from shelter technical guidance produced by the Shelter Cluster, we compiled a composite indicator of shelter design based on 7 of the 8 key messages that were produced in the aftermath of Haiyan [8]. These were based on the following shelter components: (1) foundations; (2) tie-downs; (3) bracing; (4) joints; (5) roofing; (6) site location; (7) shape. Individual components within each category were assessed based on structural observations conducted at 30 months' post-disaster. A sum of individual message sets was used to calculate an overall score for each case. We define out of set membership as averaging 3 of the messages, the crossover point as 5 messages, and in set as all 7 messages. A summary of the aggregated messages is presented in Table 1and Table 2. A summary of the calibration is presented in Figure 1 and Figure 2.

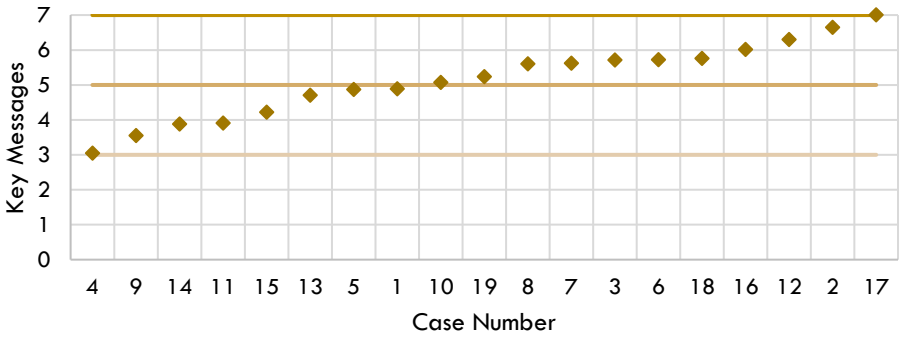

Figure 1: Threshold and Crossover Points in Direct Calibration for Shelter Design

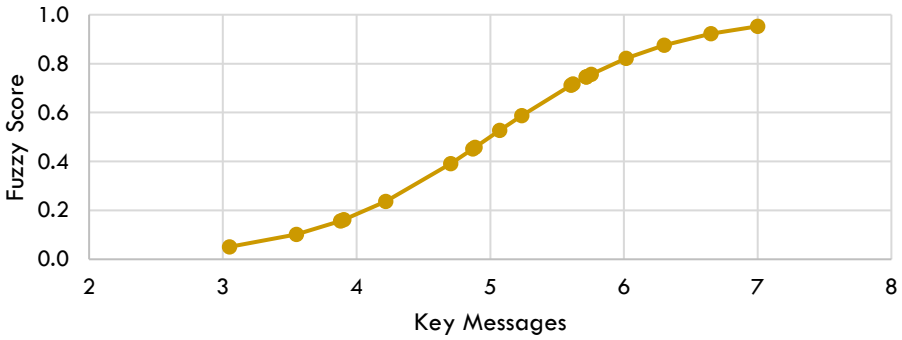

Figure 2: Calibration for Housing Design

Notes: We initially tried to simplify calibration based on building materials and key components (e.g. concrete foundations), however this did not capture small deviations and the composite of the key message proved more nuanced. The resilience of designs becomes complex when considering the robustness of different materials compared to the ability to repair damage. There is a need to expand future research to understand engineered resilience. For example, some shelters can sustain planned damage (such as wall blow outs) and these are potentially easier to rebuild. There is strong evidence from indigenous building techniques to support these safe failures in housing. Despite these claims, repeated reconstruction can be considered a major barrier to long term development of communities.

Housing Construction Quality

In contrast to housing design, construction quality assesses the adherence to standards for the type of material and building system used. There are two aspects that were used to evaluate quality of construction: (1) quality of building materials and (2) defects in construction. Weak materials, such as inappropriately selected coconut lumber (e.g. young coconuts trees or inside cuts) are unable to carry wind and seismic loads. Defects in construction include, but are not limited to, missing reinforcement in masonry construction, missing connection elements, or lack of nailing. Of the two criteria used, construction defects are used as the primary measure of in set and out of set membership as this has a greater influence over structural capacity. Poor building materials may degrade quickly, but do not have as large an impact during initial years of use – this is also less of a concern for temporary or transitional housing, assuming that these shelters will be replaced or upgraded.

Notes: The reason for adding quality was inability to explain differences in material types. For example, masonry should be more resilient (to wind at least), yet construction quality was often lacking.

Table 1: Calibration of Housing Design Components

Key Message	Sub-Category	Set Score	Description	Number of Cases	Percent Adoption
Foundation		0	Above or below ground timber post	3	16%
		0.33	Below ground timber anchors	1	5%
		0.67	Rebar tie-downs in concrete foundation	7	37%
		1	Steel strapped embedded in concrete foundation	8	42%
Tie-Down	Floor Joists	0	No connectors	0	0%
		0.7	Nailed	11	58%
		1	Metal strapping	0	0%
		N/A	Not Applicable (e.g. concrete floor)	8	42%
	Truss-Post Connections	0	No connectors	0	0%
		0.7	Nailing or rebar	14	74%
		1	Metal strapping/bolts	5	26%
	Rafter-Purlin Connection	0	No connection tie-downs	3	16%
		0.7	Wire/rope ties or timber cleats	8	42%
		1	Metal strapping/bolts	8	42%
Bracing	Trusses	0	No bracing	3	16%
		0.33	Steel wire/rebar bracing	1	5%
		0.67	Nailed timber	11	58%
		1	Strapped/bolted timber	4	21%
	Roof	0	No bracing	16	84%
		0.33	Steel wire/rebar bracing	0	0%
		0.67	Nailed timber	1	5%
		1	Strapped/bolted timber	2	11%
	Silts	0	No bracing	3	16%
		0.33	Steel wire/rebar bracing	0	0%
		0.67	Nailed timber	4	21%
		1	Strapped/bolted timber or not applicable	12	63%
	Wall	0	No bracing	8	42%
		0.33	Steel wire/rebar bracing	0	0%
		0.67	Nailed timber	8	42%
		1	Strapped/bolted timber	3	16%
	Angle	0	$\theta<30$ or $\theta>60$	7	37%
		1	$30<\theta<60$	12	63%
Joints	Joint Extensions	0	No extensions	13	68%
		1	Extension past post or not applicable	6	32%
	Notching	0	Notched more than 1/3	1	5%
		1	Notched less than 1/3 or not applicable	18	95%
	Nailing Offset	0	Nailing in-line	9	47%
		1	Nailing offset or not applicable	10	53%
	Nailing Angle	0	Nailing is straight	10	53%
		1	Nailing is at angle, screws or not applicable	9	47%
	Horizontal Joints	0	No connectors used	3	16%
		0.7	Nailing	8	42%
		1	Fishplate, straps, bolts or not applicable	8	42%
	Gusset Plates	0	No gusset plates used	10	53%
		1	Trusses include timber or steel gusset plates or not applicable	9	47%

Table 1: Calibration of Housing Design Components (cont)

Key Message	Sub-Category	Set Score	Description	Number of Cases	Percent Adoption
Roofing	Eaves	0	Longer than 45cm/1.5ft	3	16%
		1	Shorter than 45cm/1.5ft	16	84%
	Pitch	0	$\theta<15$ or $\theta>50$	2	11%
		1	$15<\theta<50$	17	89%
	Edge Nailing	0	No additional nailing provided	8	42%
		1	Additional nailing provided or not applicable	11	58%
	Overlapping Sheets	0	Sheets do not overlap	2	11%
		1	Sheets overlap or not applicable	17	89%
	Nailing	0	Regular nailing	1	5%
		0.7	Umbrella nail or wire	11	58%
		1	Twisted umbrella nail head or roofing screw	7	37%
	Shape	0	Monoslope	0	0%
		0.7	Gable	11	58%
		1	Hipped ("Quatro Aquas")	8	42%
Site	Flooding/ Storm Surge	0	Floor not raised and prone to flooding/storm surge	3	16%
		1	Silted house or not applicable	16	84%
	Rockfall/ Slopes	0	Prone to landslides/rockfall	0	0%
		1	Safe distance from landslides/rockfall or not applicable	19	100%
	Debris	0	Within distance of falling trees or other debris	3	16%
		1	Safe distance from falling debris or not applicable	16	84%
	Wind	0	Exposed to coastal winds or high on mountain	2	11%
		1	Inland or protected from winds	17	89%
Shape	Overhangs	0	Overhang on at least one wall face	0	0%
		1	No overhangs	19	100%
	Layout	0	Irregular shape	2	11%
		1	Rectangular or square shape	17	89%
	Length	0	Building at least twice as long as wide	0	0%
		1	Building does not have side more than twice width	19	100%
	Awnings	0	Awnings attached to main roof	4	21%
		1	Awnings separate from main roof	15	79%
	Building Groups	0	Housing groups trap wind	1	5%
		1	Housing groups allow for adequate wind flow	18	95%
Preparedness	Evacuation	0	No evacuation center or plan	11	58%
		1	Designated evacuation center and plan	8	42%
	Communication	0	Lacking early warning systems	0	0%
		1	Radio, television or other source of early warning	19	100%
	Supplies	0	No supplies	15	79%
		1	Medical supplies, documentation, food and/or clothing prepared	4	21%

Table 2: Composite Housing Design Assessment

Case Number	1	2	3	4	*5*	6	*7*	8	9	10	11	12	13	14	15	16	17	18	19
Overall Design (possible 7)	4.89	6.65	5.72	3.05	4.87	5.72	5.62	5.60	3.55	5.07	3.90	6.30	4.70	3.88	4.22	6.02	7.00	5.76	5.24
Calibration	0.46	0.92	0.75	0.05	0.45	0.75	0.72	0.71	0.10	0.53	0.16	0.88	0.39	0.16	0.24	0.82	0.95	0.76	0.59
Foundation	0.67	1.00	1.00	0.00	0.67	1.00	1.00	0.67	0.00	0.67	0.67	1.00	0.67	0.33	0.00	1.00	1.00	0.67	1.00
Tie-Down	0.70	0.85	0.70	0.85	0.70	0.80	0.70	1.00	0.70	0.70	0.70	0.90	0.47	0.47	0.35	0.90	1.00	0.70	0.90
Floor Joists	N/A	N/A	0.70	N/A	N/A	0.70	0.70	N/A	0.70	N/A	0.70	0.70	0.70	0.70	N/A	0.70	N/A	0.70	0.70
Truss-Post Connections	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1.00	0.70	0.70	0.70	1.00	0.70	0.70	0.70	1.00	1.00	0.70	1.00
Rafter-Purlin Connection	0.70	1.00	0.70	1.00	0.70	1.00	0.70	1.00	0.70	0.70	0.70	1.00	0.00	0.00	0.00	1.00	1.00	0.70	1.00
Bracing	0.33	1.00	0.40	0.20	0.33	0.60	0.60	0.60	0.20	0.47	0.13	0.67	0.33	0.60	0.47	0.73	1.00	0.60	0.60
Trusses	0.67	1.00	1.00	0.00	0.67	0.67	0.67	0.00	0.00	0.67	0.67	0.67	0.67	0.33	0.67	1.00	1.00	0.67	0.67
Roof	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Silts	1.00	1.00	1.00	1.00	1.00	0.67	0.67	1.00	1.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	1.00	0.67	0.67
Wall	0.00	1.00	0.00	0.00	0.00	0.67	0.67	1.00	0.00	0.00	0.00	0.67	0.00	0.67	0.67	0.67	1.00	0.67	0.67
Angle	0.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Joints	0.28	1.00	1.00	0.17	0.17	0.62	0.78	1.00	0.28	0.50	0.28	0.83	0.50	0.28	0.45	0.83	1.00	0.83	0.12
Joint Extensions	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Notching	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
Nailing Offset	0.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00
Nailing Angle	0.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00
Horizontal Joints	0.70	1.00	1.00	0.00	0.00	0.70	0.70	1.00	0.70	1.00	0.70	1.00	0.00	0.70	0.70	1.00	1.00	1.00	0.70
Gusset Plates	0.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	0.00
Roofing	0.90	1.00	0.62	0.28	1.00	0.95	0.78	0.78	0.57	0.73	0.57	0.90	0.73	0.90	0.95	1.00	1.00	0.95	0.62
Eaves	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
Pitch	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Edge Nailing	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
Overlapping Sheets	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
Nailing	0.70	1.00	0.70	0.00	1.00	0.70	1.00	1.00	0.70	0.70	0.70	0.70	0.70	0.70	1.00	1.00	1.00	0.70	0.70
Shape	0.70	1.00	1.00	0.70	1.00	1.00	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1.00	1.00	1.00	1.00

Table 2: Composite Housing Design Assessment (cont)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Overall Design (possible 7)	4.89	6.65	5.72	3.05	4.87	5.72	5.62	5.60	3.55	5.07	3.90	6.30	4.70	3.88	4.22	6.02	7.00	5.76	5.24
Calibration	0.46	0.92	0.75	0.05	0.45	0.75	0.72	0.71	0.10	0.53	0.16	0.88	0.39	0.16	0.24	0.82	0.95	0.76	0.59
Site	1.00	1.00	1.00	0.75	1.00	0.75	0.75	0.75	1.00	1.00	0.75	1.00	1.00	0.50	1.00	0.75	1.00	1.00	1.00
Flooding/Storm Surge	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.00	1.00	1.00	1.00
Rockfall/Slopes	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Debris	1.00	1.00	1.00	0.00	1.00	0.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wind	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00
Shape	1.00	0.80	1.00	0.80	1.00	1.00	1.00	0.80	0.80	1.00	0.80	1.00	1.00	0.80	1.00	0.80	1.00	1.00	1.00
Overhangs	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Layout	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Length	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Awnings	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00
Building Groups	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
Preparedness	0.33	0.67	0.33	0.33	0.67	0.33	0.33	0.67	0.33	0.67	0.33	0.33	1.00	0.67	0.33	1.00	0.67	0.67	0.67
Evacuation	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00
Communication	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Supplies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	1.00	0.00

Water Access

This condition is based on access to, and capacity of, drinking, washing, and bathing water. Sphere standards specify that every household should have a water point within 500 meters [9]. On average, this equates to approximately a 10-minute walk time. In addition to distance to source, the ability of a water source to meet a household's needs was also included using the Sphere standard of 15 liters/person/day. The ability of a water source must meet a household's needs during all months of the year, but not necessarily at any given time during the day. Water quality was excluded as no reliable data sources were available.

Notes: Initially we separated drinking water and washing/bathing water, however there was little variation between the two. There were slight differences in access to sufficient quantity, but the distances to sources were usually the same. Type of source (communal tap, private tap, etc) was initially used but was too hard to distinguish between types of sources and how one is more resilient over another.

Sanitation Access

The absence of sanitation systems poses significant threats to community health, particularly in post-disaster contexts. The rise of cholera in Haiti after the 2010 earthquake is one example of detrimental impacts of outbreaks of disease. Improved access to sanitation limits the exposure to these risks. As sanitation systems are sub-surface, potential damage is typically limited to the superstructure and thus the limiting factor is not necessarily the type or size of system, but access to such systems. The former characteristics (size and type) play a larger role in influencing maintenance.

Notes: We initially considered using the type of system (septic tank, pit latrine, etc), but this likely has greater influence over maintenance practices. Further, access to sanitation better captures the quantity (redundancy and robustness) and ability to reconstruct if damaged since damage is usually only to the superstructure (resourcefulness and rapidity).

Electrical Access

This condition covers household's access to power generation through the grid. Given the limited state of household size solar systems, these were excluded as they were cost prohibitive at the time of study for most households to power typical appliances. Power access is often inextricably linked to other infrastructures, such as water systems, and has been shown to be important for economic activity. While restoration of power was relatively uniform across all communities studied, there were variations observed who had access to connect to the power grid. As such, in set membership was defined as lack of access to the grid, slightly in set was defined as shared connections, and full membership was private connections.

Notes: While there are dozens of other metrics for measuring power system resilience, the impact of Hiayan demonstrated that the limiting factor in restoring power to communities was household connections. Electrical lines were replaced within three months, however household connections and power agreements between homeowners and power suppliers were taking years to restore. The generation capacity itself was fairly consistent across all regions studied and can be considered a domain condition. Further, we previously included a separate condition for 'alternative power systems' that could act as backups, such as solar lights. A large percentage of these were non-functional and there was quite a bit of overlap with simple access to electricity that this separate condition did not have merit.

Education Access

Travel times to both primary and high schools were used to assess education facility resilience. Most schools built after Haiyan used the same standard plan, thus there was nearly no difference in level of design across facilities. As a result, distance to the nearest school was the limiting factor when

determining resilience of educational facilities. Data from barangay officials was used to determined these transit times for the average family in a barangay.

Notes: The actual design of schools is considered to be a domain condition because the Philippine Department of Education used standardized designs nationally for all primary and high schools. The exception to this is private schools, however the majority of households surveyed could not afford to send their students to these facilities.

Medical Care Access

In order to evaluate medical care access, the travel time to the nearest hospital was used. This data was collected from barangay officials for the average family in their barangay. As all barangays studied had barangay health centres, these facilities were excluded as they would be a domain condition and they do not represent access to medical care beyond simple injuries or illnesses.

Notes: Travel time is used in place of distance to take into consideration means of transportation and income. Many households were required to take Jeepneys due to income constraints. Further road infrastructure often extended times to reach facilities. We initially considered direction calibration, but it was not required due to grouping of answers provided by barangay officials.

Transportation

The quality of infrastructure supporting transportation modes is an important aspect of infrastructure system resilience. Entirely paved roads in barangays were considered in set as these are more robust to weather-related hazards. The quality of these roads, reflected by observations of cracking and rutting, was used to measure the performance of roads infrastructure. This data was collected using a survey of barangay officials.

Evacuation Centres

We consider all sites that provide safe shelter in the face of hazards an evacuation site. These include houses, schools, barangay buildings, commercial buildings. Natural formations, such as caves, are excluded because of rare use and late evacuation times. There is significant evidence from past literature to suggest that evacuation sites must be situated within 500 meters of households in order to be viable [10]. Evacuation centres more than 500m away were also found to be commonly unused in Typhoon Ruby one year after Yolanda, thus this was distance was used form a dichotomous variable for evacuation centre access. Evacuation sites were identified through a survey of barangay officials.

Governance

We assessed resilient governance as consisting of effective and proactive planning as well as regional cooperation. Both are theorized in literature to be of equal importance, so the two conditions were averaged with equal weight.

Disaster Management Planning

Frequently cited in literature as a means to reduce risk, disaster management planning improves the ability of community response through pre-emptive measures. In particular, we used evacuation drills as a means to measure efforts to prepare for future hazards. While written disaster management plans are a first step in analysing risks, evacuation drills demonstrate putting these plans into practice. We differentiate between drills that were initiated by the barangay and external organisations as those initiated internally are theorized to have a higher chance to being sustained.

Regional Cooperation

Established relations with neighbouring barangays and municipalities allows for sharing of resources during a disaster event. Further, understanding of disaster management procedures allows for local governments to compliment neighbouring efforts, support gaps in response, and strengthen core

competencies. This was assessed by whether barangays had shared their disaster management plans, either verbally or in writing. Cooperation also included joint meetings to discuss disaster management.

Economic

Household Savings

Average savings of households in a community represents a measure of economic robustness and ability to rapidly rebound from a shock. Cash is useful as it can be used fluidly to purchase needed resources in the event of a disaster. The Philippines Statistics Authority reported that in 2015 the average family of five would need P1,582 per week in order to meet basic food needs [11]. Further, in area studied (Region VIII of the Philippines), the per capita poverty threshold was determined as P21,304 per year, or P317 per day for a family of five individuals [12]. We used these amounts to structure our set, P1,582 for full membership, P317 for the crossover point, and P0 as full non-membership. Practically, we posit that savings should cover at least one week of essential needs and that the crossover from no savings rests at one day of income at the poverty threshold. Households that have savings are able to move beyond living on simple daily income. A summary of the calibration is presented in Figure 3 and Figure 4.

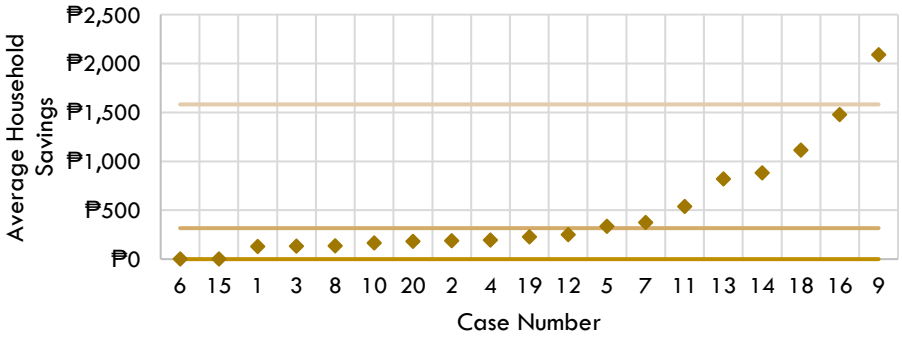

Figure 3: Threshold and Crossover Points in Direct Calibration for Household Savings

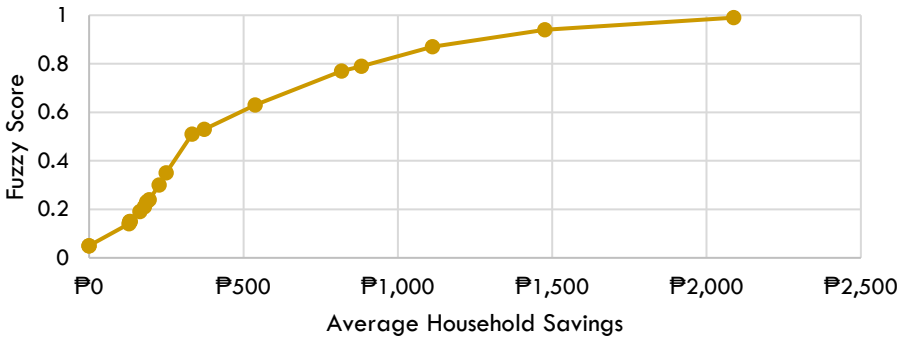

Figure 4: Calibration for Household Savings

Notes: We did not include household income here as it is a better indicator of long-term sustainability in relation to infrastructure maintenance. Further, higher incomes may be tied to industries that inherently are less resilient (e.g. coconut farming). Access to credit is a domain condition since no less than two-thirds of households in a community had access and 65% of all communities had more than 80% of households with access to credit.

Employment

Past studies have emphasized the importance of employment as an indicator of economic robustness. Here we draw from data on labour force participation rates of adults between working ages of 18

and 65. We use the most recent (2016) Philippine labour force participation rates for Region VIII, 64.3%, where the majority of communities were located as the crossover point [13]. Region VII, where the communities in Cebu were located, had a similar labour force participation rate of 65.3%. Non-membership is considered to be 50% and in set membership considered as 80%. Other studies have suggested that women's participation in the workforce could also be considered an indicator of economic resilience [7], however we found this to be highly contextual to culture and less applicable to patriarchal societies where women take a more central role in household tasks. A summary of the calibration is presented in Figure 5 and Figure 6.

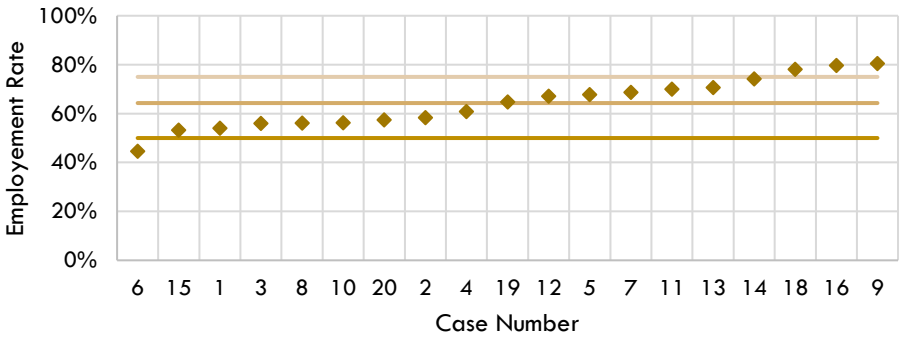

Figure 5: Threshold and Crossover Points in Direct Calibration for Employment

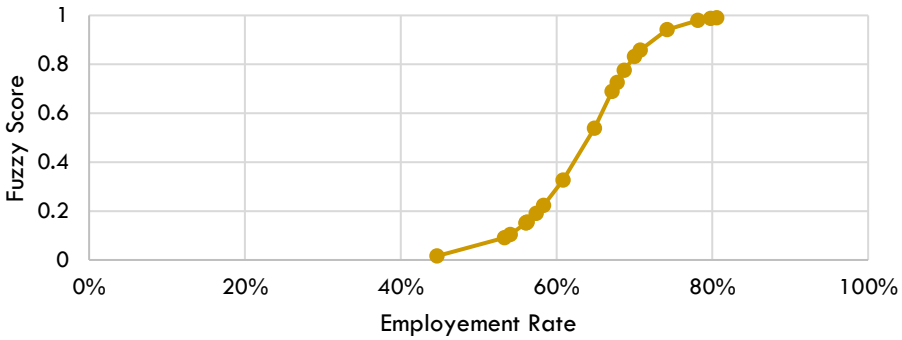

Figure 6: Calibration for Employment

Social

Social resilience is defined here as consisting of social capital, cohesion of communities (measured through birthplace), and the presence of community organisations and social mobilization. Each is equally important and is thus weighted evenly.

Social Capital

Literature has demonstrated the importance of social capital in connecting communities and increasing resilience to hazards [14]. We used the extent of shared resources to demonstrate linking, bridging, and bonding capital in practice. In set is considered intensive forms of assistance, such as medical care. These often require linking capital to mobilize barangay leaders to assist in transportation to medical facilities or access to medicines. Further, it demonstrates a high level of bonding capital where neighbours are invested in the well-being of their community. Out of set membership is considered to be information dissemination. This was found to be culturally embedded and may not apply to less collective cultures however. Sharing of cash to neighbours is used as the crossover point as it represents a liquid asset that can be used at the discretion of the household receiving assistance and shows a higher level of bonding and trust between neighbouring households.

Native to Community

We use place of birth as an indicator of social cohesion as it often signifying longer social ties. Further, in several of the urban contexts studied, new residents to a community were often located in vulnerable sites that have greater hazard exposure, demonstrating the applicability of this indicator. We used a structured set of Philippine political divisions to distinguish birthplace. Those households born in another province were considered out of set, as there are often differences in language and cultural norms. In set membership was considered birth within the barangay.

Community Organisations and Mobilization

In addition to organic social ties, established community organisations can leverage resources to respond to community needs. Out of set membership was defined as low participation in barangay meetings and the absence of community organisations. In set was defined as formalized organisations with active participation from constituents. The crossover point is informal groups that have emerged, such as social groups surrounding livelihoods as these afford many of the same benefits as established organisations but lack the same level of legitimacy and recognition from local governments.

Sustainability

Overall sustainability was taken as the average of economic, social, and environmental dimensions. Each sub-condition is weighted evenly within each respective dimension.

Economic

Household Wealth

In contrast to savings which are used to measure the economic buffer a household possesses, income represents the ability of a household to sustain and support itself. Past research [15] has pointed to a minimum level of income required to meet basic needs as a key indicator of economic sustainability. Both income and expenditure household data were collected, however expenditure data proved to be less susceptible to fluctuations. Employment for most households surveyed changed on a weekly basis and thus income changed dramatically from one week to the next. Expenditures were found to be much more consistent and 'smoothed' out fluctuations in household finances. Further, almost all money earned was observed to be spent by households on essential needs. Data for this condition were taken as the reported average weekly expenditures for households. Weekly averages were used in place of monthly or annual averages as it was easier for respondents to answer expenses on a weekly basis.

The minimum wage for Region VII, which all of the communities were located, was P235 per day for retail and service industries (the lowest of any sector) as of 2015 [16]. Other sector daily minimum wages were P260 for non-agriculture, P238 for handicraft, and P241 for agriculture (non-sugar) for reference. As of 2015 (the most recently reported data), the Philippine Statistics Authority reported that a family of five needed P6,329 per month, or P1,582 per week, to meet basic food needs [11]. Further, an income of P9,064 per month, or P2,266 per week, was needed to meet both food and non-food needs. Regionally, the annual per capita poverty threshold as of 2015 was P21,304, or P444 per capita per week [12]. The poverty threshold is based off meeting food and non-food needs.

All but one of the 19 communities studied fell below the regional poverty threshold. This threshold is considered fully in set as it represents a sustainable income level. Adjusting the national average for food needs, the per capita income required would be P316 per person per week. This value was used as out of set membership as it constituted the most basic level of necessity required for an individual. Assuming minimum wage for the average family size of five, one full time working adult (5 days a week), and one half-time working adult (2.5 days per week – part time work is common for the female head of household), the household would net P352 per capita per week. This value was used as a crossover point as it represented the standard for most households yet fell below the poverty threshold. A summary of the calibration is presented in Figure 7 and Figure 8.

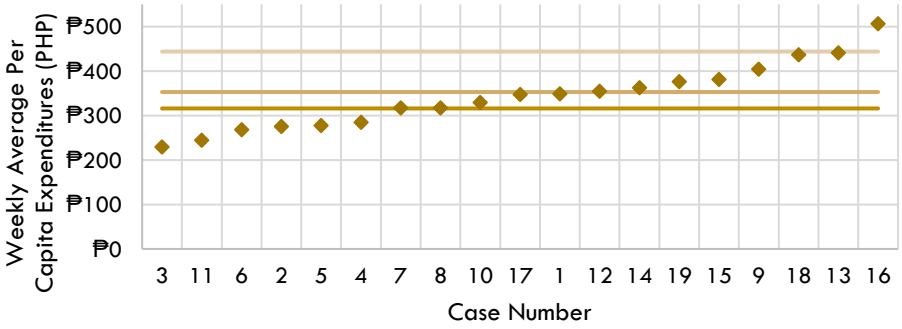

Figure 7: Threshold and Crossover Points in Direct Calibration for Household Wealth

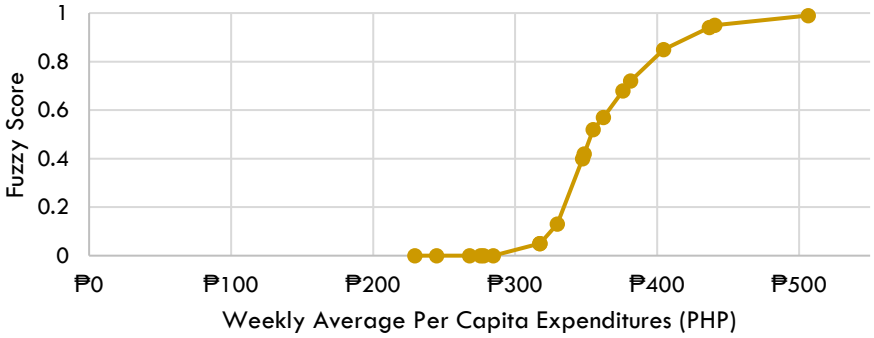

Figure 8: Calibration for Household Wealth

Notes: We initially used household expenditures, but this did not adequately take into consideration household size. For example, the community with the highest average expenditures (wealth), also had one of the largest average household sizes. A per capita wealth measure more realistically represents the ability of a household to sustain itself.

Service Interruptions

While access to water and electricity are considered as indicators of resilience [7], frequency of interruptions can be considered a metric of sustainable service provision. Regular interruptions signal that water and electrical systems are stressed on a regular basis and unable to meet the basic needs of households. Water and electricity have also been shown to increase economic production and livelihood opportunities.

Social

Land Tenure

The longevity of housing within a community is dependent upon sustainable land agreements. In particular, ownership, and to some degree formal rentals, is important to ensure that households are not evicted. Land disputes can be one cause of social disputes that arise within communities, particularly in urban areas [17]. This divide between formal and informal land use is a driver of social inequality and represents the distance of power dynamics within communities. In the Philippines there is a long history of land reinforcing social inequalities – an issue which to date remains despite numerous attempts at land reform [18].

Out of set membership was defined as informal settlement with no permission granted by the land owner. In set membership was defined as ownership, with distinction between the household having the land title and not. Rental agreements were considered to be slightly out of set. It is common in the Philippines that land rental is considered separate from ownership of the physical housing unit. As a

result, should a household be forced to move from rented land, the cost of moving the housing materials to a new site may be cost prohibitive and result in loss of significant capital.

Shelter Satisfaction

Despite improvements and lessons learned, shelter programs continue to neglect cultural suitability and homeowner needs. As a result, shelters are often abandoned, modified, or not maintained [19]. Past studies have used satisfaction of shelter as a measure of its perceived habitability [20]. As a result, we dew from survey data that asked homeowners to compare their existing house to their house before Haiyan. Household responses for each community were averaged using a 5-point weight scaled for the five categorical responses (much worse [-1], somewhat worse [-0.5], about the same [0], somewhat better [0.5], much better [1]). Ideally, shelter programs would improve living conditions, thus a response of "somewhat better" was considered to be fully in set. "About the same" was considered to be fully out of set. Despite pre-existing conditions being restored, these were often inadequate before the typhoon. An average score between the same conditions and somewhat better (a score of 0.25) was used as the crossover point as it suggests ambiguity in whether there was an improvement. A summary of the calibration is presented in Figure 9 and Figure 10.

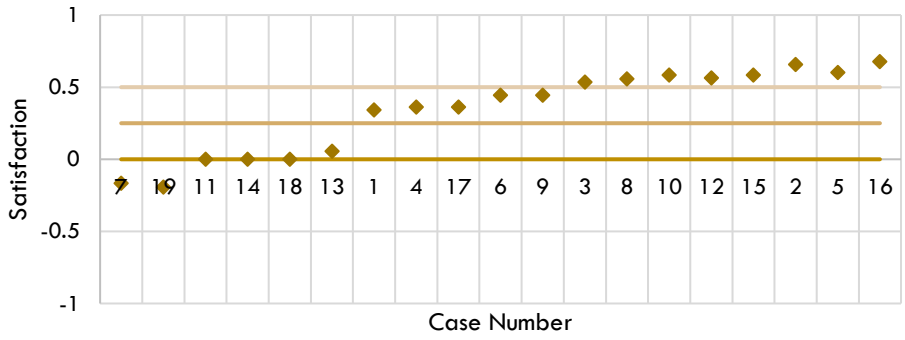

Figure 9: Threshold and Crossover Points in Direct Calibration for Satisfaction with Shelter

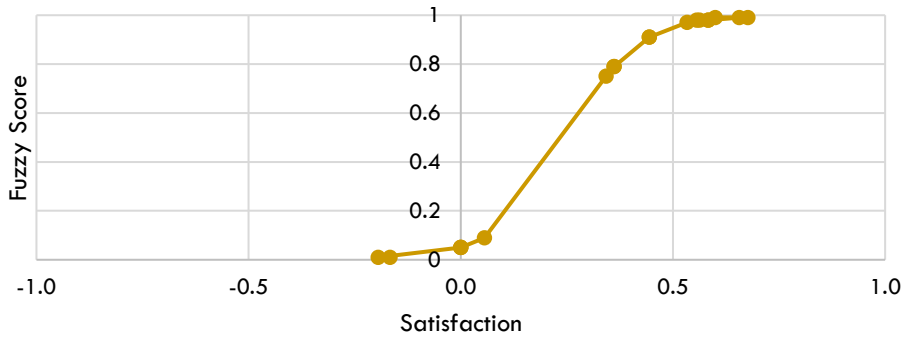

Figure 10: Calibration for Satisfaction with Shelter

Notes: Generally, satisfaction was high for programs with only two programs falling below pre-existing housing before the typhoon. Broadly this suggests that shelter assistance improved living conditions.

Environmental

Sanitation System

While institutional environmental protections are an important part of sustainability, at the community level, household sanitation (or the lack thereof) is often the largest contributor to pollution. As such, the

presence of sanitation facilities plays a significant role in improving public health, which in turn impacts quality of life. Three primary types of treatment systems were observed in the studied communities. These include unlined pit latrines, lined pit latrines, and septic tanks. Line pits typically used concrete masonry units (locally referred to as 'hollow blocks'). The distinction between lined pits and septic tanks was considered as whether or not the system had a closed bottom. The absence of any sanitation system, or widespread use of open defecation, was considered to be out of set. The use of septic tanks is the primary treatment system considered in set while lined pits are slightly in set and unlined are slightly out of set.

Building Material Sourcing

One of the most widely cited measures of infrastructure sustainability concerns the sourcing of building materials [21]. Efforts to define sustainability commonly focus on the necessity for materials to be locally available. While materials such as concrete are known to have higher initial carbon footprints than other materials such as timber, there is still ongoing debate about which of these materials is more sustainable when considered in life cycle analysis (LCA). Beyond the obvious reduction in transportation emissions from sourcing materials locally, there are a host of other benefits derived including supporting local economies and a construction workforce knowledge in building types.

Out of set was considered to be the inability to obtain a significant portion of the building materials and components (e.g. strapping) locally. In set was defined as all of the building materials and components could be found locally. The primary distinction between in set and out of set membership was whether or not all of the primary building materials (frame, wall, and roofing) were available in local markets. The availability of materials was based off market observations 30 months' post-disaster.

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