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Revealing (mis)alignments between household perceptions and engineering assessments of post-disaster housing safety in typhoons

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ABSTRACT

Building capacity for disaster risk reduction requires integrating local and scientific knowledge. We focus on local and scientific knowledge of the safety of housing in typhoons' wind, focusing on roof and wall systems. To identify alignments and misalignments between household and engineering understanding of safe housing, we conducted semi-structured interviews with 170 households that received new houses from organizations following Typhoon Yolanda in the Philippines. We qualitatively coded and analyzed these interviews to identify what housing components households expect to fail first, their preferred failure, and how they plan to modify their house to be safer in typhoons. We compared these responses to three results from engineering assessments: the governing failure mode, the failure mode that best meets safety performance objectives, and the quantified impact of design modifications. Household perceptions and engineering assessments were well-aligned when focusing on the damage expected to a single component and how to improve the performance of a single component. However, perceptions and assessments were misaligned at the housing level as households did not consider how housing components worked together as a system to influence performance. Households often did not recognize that modifying one component, such as the roof, would have an adverse impact on the performance of other components, such as the wall. This study is one of the first to systematically compare perceptions and assessments of housing safety and advances understanding of alignment, or misalignment, of local and scientific knowledge of safe building practices. We recommend that future post-disaster training programs incorporate discussions of a house's load path to focus on how components work together, enabling design and modification decisions that support improved housing performance.

1. Introduction

Since the 2004 Indian Ocean tsunami, discussion of post-disaster housing reconstruction has focused on "building back better," with emphases on creating structures that are more resilient than they were before a disaster and supporting disaster risk reduction (DRR) [1]. An essential goal of DRR is to improve local capacity, or the "combination of all the strengths and resources available within a community that can reduce the level of risk, or the effects of a disaster" [[2], p. 16]. Post-disaster housing programs can help build capacity by providing new, hazard-resistant houses, by hiring local builders to assist in rebuilding houses, and by improving households' knowledge of how to build safely. The latter is critically important for supporting the long-term capacity of a community to construct and maintain safe housing [3]. Even when organizations can directly provide a new house, training for safe housing design is fundamental, as households are likely to modify their houses to better suit their needs, and, if done improperly, these modifications can decrease the safety of the house [4]. Furthermore, households that receive no assistance, comprising at least 70% of households affected by disasters [5], frequently mimic the reconstruction practices they witness by organization-assisted households [6].

Post-disaster housing programs can promote local capacity and respond to calls in development and DRR literature [e.g. Ref. [7,8]] by integrating engineering assessments and local knowledge of safe housing. Engineering assessments [e.g. Ref. [9]] can advance safe building practices by identifying structural vulnerabilities to hazard events and testing design alternatives that will improve hazard performance. Organizations then share engineering knowledge through training and messaging campaigns [e.g. Ref. [10,11]]. In 2018, the Global Shelter Cluster, the global agency responsible for the coordination of

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post-disaster shelter responses, reiterated the vital need for organizations to understand the local context [12] and building culture [13], and their influence on post-disaster housing and its safety.

To build local capacity through integration of engineering assessments and local knowledge, we seek to understand local knowledge of safe housing, compare this to engineering safety assessments of local housing, and identify alignments and misalignments between the two. To do this, we examine local perceptions of housing safety in typhoons in six communities in the Philippines and compare these perceptions to wind engineering assessments of the housing designs constructed by organizations in these communities to answer our research question:

How do local perceptions and engineering assessments of safe post-disaster housing align and misalign?

We focus on a specific performance objective, housing safety, and define a safe house as one that will not be damaged in a way that causes injury or loss of life [14] and can still be occupied [15] after a typhoon. Furthermore, in this study, we focus on local knowledge and engineering assessments of a house's roof and wall systems in wind events, as these two systems are the most important for housing safety and the most likely to be damaged by wind in the frequent typhoons of the Philippines [9]. We focus only on the wind hazard of typhoons in this study and do not include flooding, storm surge, and wind-borne debris hazards. Identifying these alignments addresses calls to use both local and scientific knowledge to improve local capacity [e.g. Ref. [7]]. In particular, we posit that organizations need to understand local knowledge [e.g. Ref. [16,17]] to address potential misalignments between local knowledge and engineering assessments in post-disaster housing programs. Doing so will create locally accepted, feasible, and sustainable housing designs and foster long-term capacity to build and maintain a safe house.

2. Background

Mercer et al. [17] define local knowledge as "knowledge existing within or acquired by local people over a period of time through accumulation of experiences, society-nature relations, community practices and institutions, and by passing it down through generations" (p. 217). Recent studies have shown how local knowledge supports DRR, in particular, management and adaptation to fires [18], flooding [19–21], and climate change [22,23]. In these cases, local knowledge of the landscape and weather patterns informed the plans developed by professionals and scientists to mitigate and manage hazards. Knowledge of critical local landmarks helped firefighters establish a plan to control the spread of a wildfire [18]; participatory mapping exercises helped community members to work with scientists to place early flood-warning systems in the most advantageous sites around a community [19]; and, conversations with local fisherman revealed that combining their knowledge of approaching storms with other warning systems could validate storm warnings and encourage more people to evacuate before a hurricane [22].

In the context of safe construction practices, we define local knowledge as referring to what housing people perceive to be safe or vulnerable, their understanding of how to build a house safely, and what housing components people expect to be damaged. This knowledge can be learned from familial or community stories, observing construction, and experiencing housing damage in a disaster. Local knowledge of hazard location and frequency, material cost and availability, and locally-sustainable construction practices is critically valuable and can be understood by organizations to tailor their programs to the specific local needs [23,24].

Scientific and engineering knowledge, or technical knowledge, on the other hand, is knowledge that may not be endogenous to a community [8]. This knowledge also plays an important role in DRR. For example, messaging campaigns based on engineering assessments [10, 11] can be used to complement local knowledge in communities with few engineers, where knowledge on how to safely design and build hazard-resistant structures might be limited [25]. Moreover, technical guidance can support households in making future decisions about housing modifications that will improve the safety of their house [4].

In recent years, many scholars have discussed the importance of integrating local and scientific knowledge to reduce disaster risk [e.g. Ref. [8,16,24]] and proposed frameworks [e.g. Ref. [16,17]] for doing so. Both are valid forms of knowledge that are essential for disaster risk reduction and housing reconstruction. Local knowledge is not ignorance or lack of scientific knowledge, but rather a tacit, contextualized understanding that involves applied wisdom or good judgment that develops in everyday life [26]. Outsiders will never be able to fully appreciate this understanding, but they can coordinate with community members to integrate local knowledge into their practices. Scientific knowledge is also essential as it can introduce new ideas for safe construction and introduce practices to reduce housing vulnerabilities. In this study, we focus on identifying (mis)alignments by comparing local perceptions of safe housing with scientific knowledge from engineering assessments.

2.1. Perceptions of safe housing

This study focuses on uncovering local perceptions of safe housing as the basis for understanding alignments. This topic has been understudied, with few researchers investigating what households perceive to be safe [27]. For example, previous studies used surveys to assess hurricane and earthquake risk perceptions, including a single question on whether households thought their house was safe [28] or would be damaged [29] in a future hazard event. Some organization-led assessments have expanded this question to ask about multiple hazards. For instance, CARE India assessed post-disaster housing projects, asking households how resistant they thought their new house was to three types of hazards, finding that an overwhelming majority perceived their house to be hazard-resistant [30]. Yet, these studies did not provide detailed information about what design details led people to feel safe or unsafe in their house or how they might modify their house to improve its safety—information that is needed to identify alignments between engineering and local knowledge.

Recognizing these limitations in the literature, we [27] previously studied perceptions of post-disaster housing safety in the Philippines. Using surveys explicitly focused on the amount of damage respondents expected to four different housing components (foundations, walls, roof coverings, and roof structures), we showed that most people expected damage to both the roof covering and roof structure from winds in a typhoon. Household expectations of wall damage varied; some respondents expected no damage to their walls while others expected a typhoon to destroy their walls completely. We also found that the material of a house's structural system (e.g., concrete or wood) had a significant influence on the damage expected. While this work improved our understanding of local perceptions of safe housing, it did not uncover what components households expected to fail first or, if damage were to occur, what type of damage households thought would be the most preferred or least catastrophic. Importantly, this study also did not compare these perceptions to engineering assessments of the houses. The goal of the present study is to expand on these perceptions to understand why they exist and how they align or misalign with engineering assessments.

2.2. Alignment of local perceptions and engineering assessments

There is a dearth of information on whether household perceptions of safe housing align or misalign with engineering assessments of safe housing. Yet, anecdotes from previous work illustrate differences in what households and engineering assessments know to be safe. These prior studies show that past experiences and priorities other than safety drive these differences.

Dalisay and De Guzman's [31] studied people's decisions to evacuate during Typhoon Yolanda, finding that perceptions of housing safety are tied to the height and material of the house and the household's previous disaster experience. Specifically, they found that most people perceived concrete structures with at least three stories to be safe because these structures had performed well in previous typhoons, especially when compared to single-story houses made of light materials, which had been largely destroyed [31]. While this perception of typhoon safety is not necessarily at odds with engineering judgment, if not constructed correctly, including with adequate reinforcement, this type of structure can be vulnerable in an earthquake. This example highlights how people's experiences with hazards influence their perceptions and can lead them to focus more on safety in one type of hazard event than another.

Another example of misalignments between people's perceptions of concrete houses and engineering assessments comes from Arlikatti and Andrew's [32] study of housing recovery in India after the 2004 tsunami. Households who had received new houses with masonry walls and flat concrete roofs reported feeling less secure in their house compared to households whose new houses had roofs made of plastic sheets or thatch [32]. Although concrete roofs are expected to perform better than thatch roofs in strong winds, people held a worse perception of concrete roofs due to their lived experiences in the new homes: the concrete roofs had poor ventilation, which made the houses hot and uncomfortable. Thus, while these new houses were likely safer than households' previous houses, they did not address other needs, such as comfort, and created negative perceptions of the material.

Lastly, a study of informal housing in Istanbul found that people who built their own houses perceived their houses to be much safer than houses built by local engineers. However, because those who self-built their homes were not trained in seismic design, their houses often lacked adequate reinforcement and concrete cover over the reinforcement and used poor quality concrete; as a result, these houses were likely seismically vulnerable [33]. Nevertheless, because they built their houses themselves and did not use engineers, who were perceived to be corrupt and ineffective, they thought the houses were safe.

These three examples indicate that household perceptions and engineering assessments of safe housing do not always align and that, at times, households' perceptions could negatively affect the long-term safety of the houses in future hazard events. Additionally, these studies highlight that misalignments in household perceptions and engineering assessments focus on design details, especially related to roofs, walls, and materials. This research addresses the need to more fully understand the relationship between perceptions and assessments by systematically comparing perceptions and assessments of roof, wall systems, and material details to identify where they align and misalign and what factors influence the misalignments.

3. Context

Our study focuses on the (mis)alignments between household perceptions and engineering assessments of housing safety in six communities in the Eastern Visayas, Philippines. These communities were affected by Typhoon Yolanda, which made landfall on November 8, 2013, affecting over 16 million people [34] and damaging or destroying 1.1 million houses [35]. After the typhoon, governmental and international nongovernmental organizations (NGOs) mobilized to assist households in rebuilding. This assistance included directly building new houses, providing training, and supporting self-recovery with cash and materials [36]. Some communities were relocated from beachfront locations to sites away from the coastline [37].

During reconstruction after Typhoon Yolanda, organizations or government agencies provided assistance to specific communities, and we selected six communities that received new houses from either the government or NGOs. These assisting organizations used different housing designs and program approaches across the communities, but within a single community, beneficiary households received the same or similar houses. Not all households in a community necessarily received assistance, but we included only those households who had received a house from an organization following Yolanda in this study. The housing designs in these communities are both one- and two-story houses built with wood, concrete, and/or masonry. We anticipate that these height and material differences will be important for households' understanding of safe housing [27,31]. Fig. 1 shows photos of some of the studied houses. Additionally, some programs provided training and required household participation in the rebuilding process, while others neither provided training nor supported participation. Table 1 summarizes the characteristics of each community and the post-Yolanda reconstruction program.

The Eastern Visayas region, and, thus, the communities in this study, is susceptible to both earthquakes and typhoons and has experienced both in recent years, as shown in Fig. 2. Of particular note is Typhoon Ursula, which struck the islands of Eastern Samar and Leyte on December 24, 2019, following a similar path to Typhoon Yolanda. Ursula damaged over 428,000 houses [38], including some in the communities in this study.

4. Methods

This study uses both semi-structured interviews and wind engineering performance assessments to identify (mis)alignments between household perceptions and engineering assessments of safe housing in a typhoon, as illustrated in Fig. 3. An alignment is identified if what households perceive to be safe or how they would modify their house to make it safer agrees with engineering assessments. A misalignment is identified if household perceptions and engineering assessments disagree on whether a component or modification is safe in a typhoon.

4.1. Data collection of household perceptions

Data on local perceptions of safe housing were collected through semi-structured interviews with households that received new houses from NGOs or the local government. Pilot interviews conducted in September 2019 aided in the development of the questions asked in the 2020 interviews. We conducted 170 interviews with households across the six communities in January and February 2020. We selected households to interview first through cluster sampling where we divided a community into geographic clusters and interviewed households in each cluster. We then used snowball sampling, asking respondents if there were other households in their community who had different or notable experiences in recent typhoons that we could interview. We stopped interviewing in each community once we had reached theoretical saturation when we stopped hearing new responses to questions about perceptions of housing safety. Local research assistants conducted interviews in the local language, Waray-Waray. Each interview lasted between 20 and 50 minutes and was conducted either inside or outside the respondent's house. Approximately two-thirds of the respondents were women. All but two respondents consented to be audio recorded, and recordings were transcribed and translated for data analysis. Table 1 reports the number of respondents interviewed per community.

We asked respondents open-ended questions to capture detailed responses and rationale. Results from a previous survey [27] revealed that housing material, participation in construction, and prior experience were factors that influenced household perceptions of safe housing, so we incorporated questions that asked about these when designing the interviews. A majority of questions focused on what respondents perceived to be safe or unsafe about a house, and other questions sought to understand why they might hold these perceptions. We used ethnographic interviewing techniques [40] to first ask respondents broad questions, such as, "Can you tell me a story about a time you felt safe in your house?" and, "Can you describe a house that is less safe than your house?" and then moved on to more specific questions, such as "What in your house do you think would be damaged first in a typhoon?" and "How would you make your house safer in a typhoon?" We asked these two questions to make direct comparisons to the results of the

Fig. 1. Photos of the studied houses, illustrating the variety of materials, shapes, and heights used: a) two-story wood house with hip roof, b) loftable masonry house, c) two-story wood house with a gable roof, d) one-story wood house with plywood walls, and e) one-story wood house with amakan walls.

Table 1
Summary of communities selected for this study.

Community[a]	Municipality, Province	Implementing Organization	Relocated?	Participation in Housing Reconstruction (data from Ref. [39])	Training Program (data from Ref. [39])	# of Stories	Main Structural Material	# of Households Assisted	# of Interviews
San Pablo	Tacloban, Leyte	NGO	No	Households participated heavily in planning, design, and construction oversight	Households received no formal training but often observed the construction	1 or 2	Wood	42	14
Sagasumbut	Tacloban, Leyte	NGO	No	Households participated heavily in planning, design, material procurement, and construction oversight	Households received formal construction training	1 or 2	Wood	484	35
Linao	Tacloban, Leyte	Government	Yes	Households did not participate in reconstruction	Households received no training	Loftable[b]	Reinforced concrete	1000	19
Tolosa	Tacloban, Leyte	Government	Yes	Households did not participate in the reconstruction	Households received no training	Loftable[b]	Reinforced concrete	558	60
Sohoton	Guiuan, Eastern Samar	NGO	No	Households participated heavily throughout the entire reconstruction process	Households received formal construction training, including hands-on demonstrations	1	Reinforced concrete or wood	63	23
Caputian	Guiuan, Eastern Samar	NGO & Government	Yes	Households were rarely involved in the reconstruction process	Households received no training	1	Reinforced concrete or wood	119	19

[a] Pseudonyms are used in place of community or regional names.
[b] Built as one-story houses but designed to accommodate two stories.

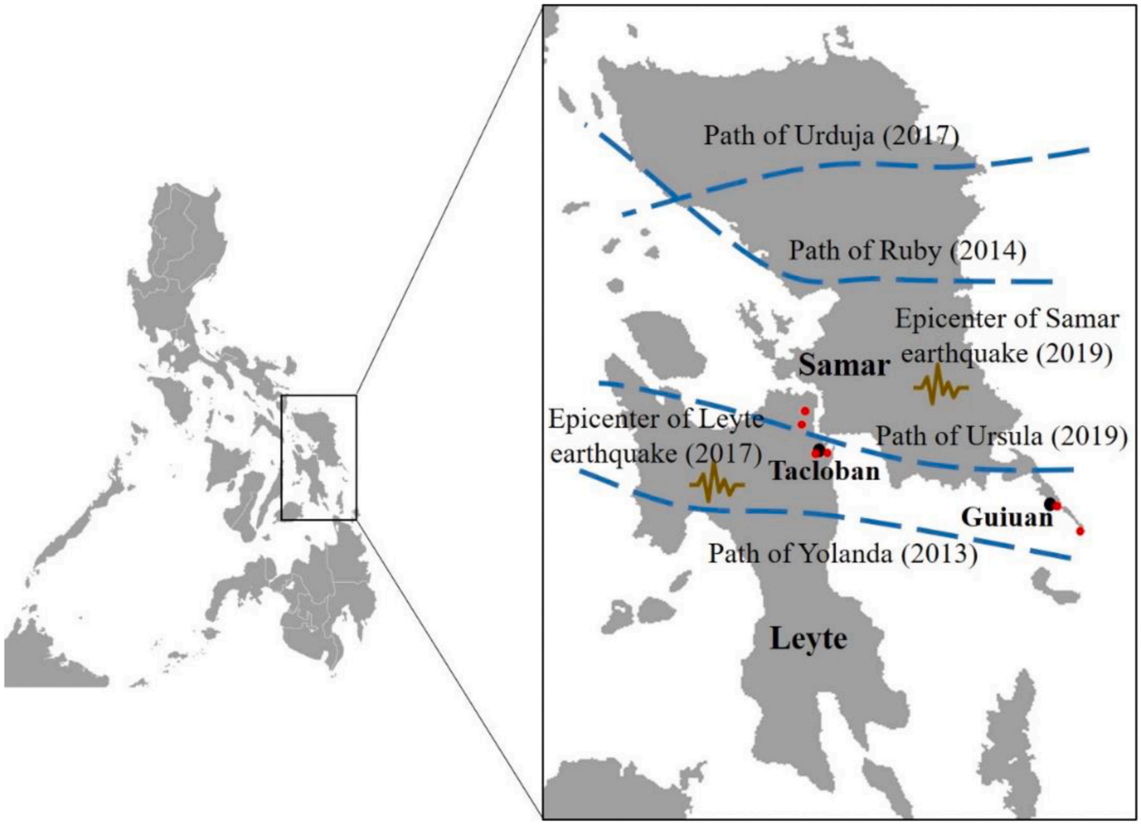

Fig. 2. Location of communities (red dots) and recent hurricanes and earthquakes. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

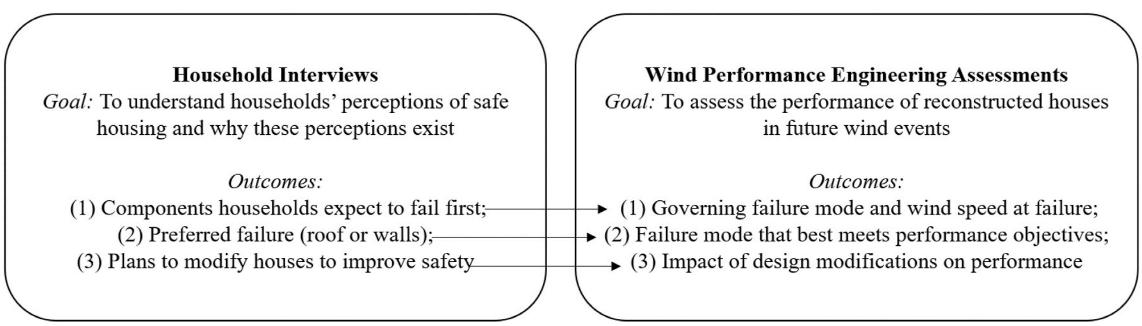

Fig. 3. Summary of data sets used to identify mis (alignments). Arrows indicate the specific comparisons made between the data from the household interviews and from wind engineering performance assessments.

engineering assessments. After observing the damage caused by Typhoon Ursula, we also asked respondents to describe their experience during Ursula, how they would prepare for another storm like Ursula, and whether they would prefer their walls or roof to be damaged: "Here are two possible situations – 1) the roof of your house fails, but the walls remain intact or 2) the walls collapse but the roof remains intact. Which would be better? Why?" Throughout the interviews, we asked follow-up questions to gain more clarity on respondents' perceptions and how they came to hold these perceptions.

4.2. Analysis of household perceptions

We transcribed nearly 70 hours of audio recordings from 170 interviews for analysis in NVivo QSR, a qualitative coding software. Our coding scheme was mostly deductive in that the macrocodes were selected to facilitate comparison to the engineering assessment results. Accordingly, we began by deductively coding the transcripts into categories of *expected damage, preferred damage,* and *completed/planned modifications* (Fig. 3). For instance, when households talked about what type of damage they might expect to happen to their house in a typhoon, we coded this as *expected damage.* Responses to questions about what housing components households would prefer to be damaged first were coded under *preferred damage.* Discussion of how households had already modified or planned to modify their house were coded into *completed/planned modifications.* Additional codes of *thinks is safe, thinks is unsafe,* and *reason for perception* were used to support the explanation of why alignments or misalignments occur. Respondents' discussion of how they feel in their house during a typhoon or earthquake, what they think is a safe/unsafe house, and what they said about specific materials or components were coded to *thinks is safe/unsafe*. After categorizing data into the macrocodes, we inductively coded responses within each macrocode into emergent subthemes. For example, under *reason for perception*, we identified *previous damage to one's own house, observations of damage to other houses, training from organization,* and *heard/saw on the* *news* as reasons respondents held the perceptions they did.

References to materials (e.g., concrete and coconut lumber) and housing components (e.g., foundations and walls) were double coded, meaning they were coded into the appropriate macro-code described above and into a material or component code, to allow for querying the responses related to a specific material or component. For example, the following response—"*For me, I think it will be safer if the roof is fully cemented as well so that during typhoons, I don't worry anymore that it might be damaged or destroyed*"—was coded into *thinks is safe, concrete*, and *roofs.* We used the "query" function in NVivo to discern broader trends both within and across the studied communities based upon response content and the relative frequency of responses in different categories.

We compared *expected damage* and *completed/planned modifications* directly to the engineering assessments and discuss these comparisons below. We also compared households' *preferred damage* to engineering perspectives of what failure mode best meets the desired performance objective (safety, in this study). Responses coded into *thinks is safe/unsafe, reason for perception,* and specific materials were used to provide explanation for why (mis)alignments occurred. We explain these comparisons further in section 4.4, Analysis of (Mis)Alignments.

4.3. Wind engineering performance assessments

We compared household perceptions to engineering assessments of the houses' wind performance [9,41]. Preventing all damage to buildings in a hazard event is cost-prohibitive, even in relatively wealthy societies [42]. Therefore, the dominant philosophy of disaster-resilient engineering design is to design structures to be damaged in a way that achieves defined performance objectives [43]. Here, the performance objective of interest is protection of life safety [44]. For housing damage in typhoons, the damage state that best achieves this objective is roof panel loss because roof panel damage can potentially prevent wall damage and is not likely to threaten the stability of the overall structure and occupant safety; although, flying panels can cause injury. Wall failure is expected to cause the most damage and threaten occupant safety [15].

From these assessments, we identified what housing component (roof panel, roof-to-wall connection, or wall frame) would fail first in a future typhoon, referred to as the governing failure mode and summarized in Table 2. The assessment also quantifies at what wind speed this was likely to occur. Additionally, these assessments explored how modifications to the housing designs would affect wind performance. Fig. 4 depicts the housing components discussed throughout this paper.

These assessments indicate that for most of the housing designs, the governing failure mode is loss of the roof panels, which occurs at wind speeds equivalent to a signal 3 typhoon in the Philippines (121–170 kph (74–105 mph), or a category 1 or 2 hurricane in the United States). For hip roofs (those sloping on all four sides, e.g. Fig. 1a), roof panel loss occurs because of failure at the interface of the roof panel and the fasteners securing the panels to the purlins. For gable roofs (those sloping on two sides, e.g., Fig. 1), panel loss occurs due to failure at the connection between the purlin and truss.

Table 2
Summary of governing failure modes for each housing design from wind engineering performance assessments [9,41].

Housing Design	Governing Failure Mode
Caputian (with wooden wall frames)	Wall failure
Caputian (with concrete wall frames)	Panel and purlin loss[a]
Linao	Panel loss[b]
Sagasumbut (1-story)	Panel loss[b]
Sagasumbut (2-story)	Wall failure
Sagasumbut (2-story, duplex)	Panel loss[b]
San Pablo	Panel and purlin loss[a]
Sohoton (with amakan walls)	Panel and purlin loss[a]
Sohoton (with plywood walls)	Panel and purlin loss[a]
Tolosa	Panel loss[b]

[a] Panel loss due to failure at the purlin-to-truss connection.
[b] Panel loss due to failure at the panel-fastener interface.

For three of the wooden house designs, the governing failure mode identified in the wind engineering assessment is wall frame failure. Wall failure indicates that the wall frame cannot resist the lateral wind loads and the walls have racked or collapsed. As a result, wall failure is the most catastrophic failure mode as it is likely to lead to the collapse of the entire house and poses the greatest threat to occupant safety and loss of habitability [15]. This failure mode occurs at wind speeds equivalent to a signal 2 or signal 3 typhoon for these houses. We observed houses in Caputian that failed in the recent Typhoon Ursula (signal 3 storm). These walls had amakan, or woven-bamboo, wall material (e.g., Fig. 1e) covering the wall framing systems. Amakan is durable enough to withstand the wind and transfer the wind loads into the wall frames (meaning, it does not blow out in the storm), but not strong enough to add capacity to the wall frames to help resist wind loads, leading the houses to collapse. The assumption in the engineering assessments was that the walls of the concrete and masonry houses would not fail in a typhoon because, in all communities, they were well-constructed with ring beams around the top of the walls. These beams help to prevent the wall from collapsing due to uplift forces from the roof [45]. Failure of the connection between the roof and wall is not the controlling failure mode in any of the studied designs.

In the engineering assessments, we also assessed the influence of possible design modifications on performance by altering connection properties, fastener spacing, and panel thickness. The most cost-effective design changes to enhance safety included decreasing the spacing between the panel fasteners, increasing the thickness of the roof panels, and installing hurricane straps. However, importantly, modifying the roof to improve its performance is advantageous only if the wall system has adequate capacity to resist the increased loads caused by a stronger roof; in fact, strengthening the roof of a weak wall-frame system can be catastrophic.

4.4. Analysis of (Mis)alignments

We compared household perceptions and engineering assessments to uncover where they agreed and disagreed, as described in Fig. 3. First, we compared households' expected failure mode and the governing failure mode from the engineering assessments. For example, when the engineering wind assessment revealed panel loss as the governing failure for a house type, if more than half of respondents living in that type of housing expected roof panel loss to occur first, we identified an alignment. However, if more than 50% of these respondents instead expected wall failure to occur first, we identified a misalignment. We also made comparisons between households' preferred failure mode and the failure mode that best meets the safety performance objectives. This comparison focused on whether households would prefer their roof or wall be damaged first and how this preference related to the engineering performance objectives. Lastly, we compared households' plans to modify their house to improve safety and the assessed impact of design modifications. For these last two comparisons, we identified a misalignment if multiple (more than two) respondents stated preferences or modification plans that disagreed with the recommendations from the engineering wind assessment. Comparisons, and the following discussion, focused on perceptions and engineering assessments of roof and wall systems, as these are the design details that most affect housing safety in typhoons.

5. Results

This study identified three primary areas where household perceptions and engineering assessments of safe housing in future typhoons aligned and misaligned: expected failure mode, preferred failure mode, and modifications to improve housing safety.

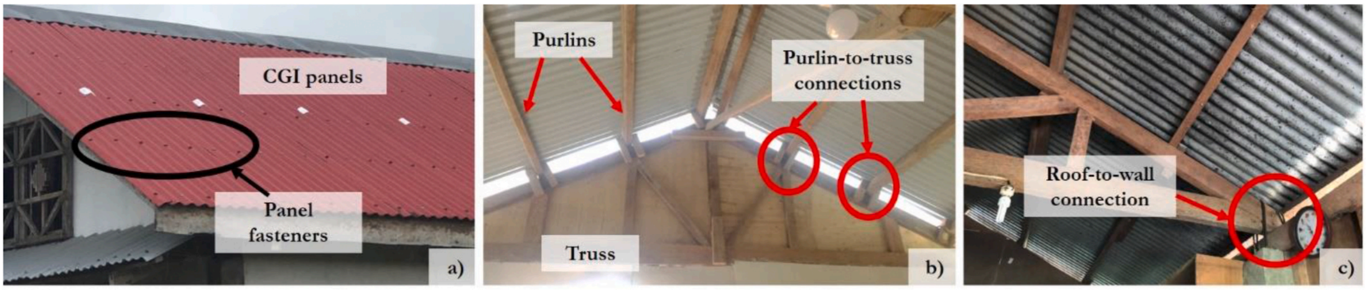

Fig. 4. Photos of common roof components showing: a) roof (CGI) panels and panel fasteners, b) purlins, purlin-to-truss connections, and a truss, and c) a roof-to-wall connection.

5.1. Expected failure mode

The engineering assessments indicated that roof panel loss was the governing failure mode for 80% of the house designs included in this study (Table 2) [9,41]. Household perceptions aligned well with the overall finding from the engineering assessments, as 76% of the 139 households who responded to the question "What part of your house do you think would be damaged first in a typhoon?" said they expected the roof panels would fail first. Table 3 shows the relative frequency of how many households expected each failure mode.

The reason respondents provided for citing roof panel failure first was past experience—they had previously witnessed this type of damage in other typhoons. For example, a woman in Sagasumbut told us: "*If it's [the typhoon] really strong, I think the first that will get destroyed is the roof and ceiling because during Typhoon Yolanda our roof was the first one to fall and get washed out*." Another woman in the same community stated, "*I guess it's the roof because it has been affected by typhoons many times. The tendency of that is the nails might have been loosening up*." These responses highlight how people draw on their previous experiences to predict what will happen in future hazard events, confirming findings from other studies, which found prior experience to be one of the most significant factors for perceived risk [46].

The engineering assessments distinguish between roof panels that failed because of failure at the panel-fastener interface ("roof panels" in Table 3) and those that failed at the connection between the purlin and the remaining roof structure ("roof panels and purlins together" in Table 3). In 40% of housing types, it is expected that both panels and purlins would be removed because of failure at the purlin-to-truss connection (Table 2) [9,41]; however, only 17% of the respondents indicated this as their expected failure mode (Table 3). Those who expected the panels and purlins said it was because of past experience, as evidenced in an interview with a woman in San Pablo:

Respondent: I guess the roof will be damaged first.

Interviewer: Are the wood purlins included or only the CGI?

Respondent: Both, just like what happened to us back then—the roof flew off.

Interviewer: Together at the same time?

Respondent: Yes.

Whether only the roof panels fail first or the roof panels and purlins fail together depends on the relative strength of the connections at the panel-fastener interface and those connecting the purlin and truss. Although only a few respondents talked about the strength of the connections as the reason for a given failure, there were a few exceptions. For example, one man in San Pablo did talk about connections as the reason for panel and purlin failure:

> "It [the purlins] would be included. It would blow off. If there is a typhoon with strong winds, the sim [CGI panels] and wood connections would be damaged together. It would blow off. There are also others [houses] where the sim would only be damaged because it is not nailed in a good way. But this one, they nailed it neatly. The sim they used are big with nails that have a cap."

Since most of the responding households did not discuss connections in either what they expect to fail or the reason for component failure, households' predictions of what component will fail first are aligned, but the understanding of why these components will fail first is not.

Ten percent of the total respondents expected wall failure to occur first. The engineering assessments found that wall failure was the governing failure mode in 20% of the housing designs, which represents 7% of the respondents based upon their housing design. To explore this issue in more detail, we grouped household responses into these three categories based on the engineering assessments of how the house they live in is expected to fail, shown in Table 4. Misalignments arise when we group respondents by their house design and compare their expected failure mode with the governing failures from the engineering assessments.

Household perceptions and engineering assessments were relatively aligned for households living in housing designs where roof panel loss was the governing failure mode, with 63% of respondents living in these housing designs expecting roof panel loss to occur first. However, as discussed above, people underestimated the likelihood of both the panels and purlins failing. Only 16% of the respondents living in housing

Table 3
Relative frequency of households' expected failure mode in typhoon winds.

Expected Failure Mode	Relative Frequency
Roof panels	59%
Roof panels and purlins together	17%
Walls	10%
Other (e.g., gutter or extension)	7%
Windows or doors	4%
Roof truss	2%
Purlins	1%
	n = 139

Table 4
Relative frequency of households' expected failure mode, grouped by the governing failure mode determined by the engineering assessment for the households' housing design. Italicized percentages represent respondents whose expected failure matches the governing failure mode for their housing design.

Households' expected failure mode	Governing failure mode based on engineering assessment of household's house design:		
	Roof panel loss	Roof panels and purlin loss	Wall Failure
Roof panels	*63%*	40%	70%
Roof panels and purlins together	17%	*16%*	20%
Walls	5%	36%	*0%*
Other (e.g., gutter or extension)	9%	4%	0%
Windows or doors	5%	0%	0%
Roof truss	2%	0%	10%
Purlins	0%	4%	0%
	n = 102	n = 25	n = 10

designs with this governing failure mode expected both the panels and purlins to fail first.

According to the engineering assessment, wall failure was the governing failure mode only in wooden houses, most notably those with amakan walls [9,41]. In the cases where wall failure is the governing failure mechanism according to engineering assessments, we found a misalignment because households do not expect the walls to fail first; instead, they expect panel or panel and purlin loss to occur first.

In communities where loss of the roof panels and purlins together was the governing failure mode from the engineering assessment, over 35% of respondents expected wall failure to govern. A majority of these respondents were in two-story houses in San Pablo, which had amakan walls on the second story. They expected wall failure because the amakan had already deteriorated due to rain exposure. As one woman in San Pablo responded to the question of what would fail first, "*Maybe the walls upstairs. They are already damaged due to frequent rain*." Amakan is viewed as an inferior material because it allows rain into the house, causing issues with comfort and livability for the occupants. However, organizations had a positive view of amakan, which was revealed to be a misalignment during Typhoon Ursula. One woman in San Pablo explained, *"Back then, [the implementing organization] told us that amakan is safer during typhoons because the wind would just go through the holes."* During Typhoon Ursula, however, the wind did not "just go through the holes", but instead collapsed the house. Thus, organizations' view of the wind performance of amakan walls is misaligned with the walls' actual performance.

5.2. Preferred failure mode

Ninety-three households responded to the question: "If you had to choose either your wall or roof to be damaged in a hazard event, which would you prefer?" Sixty percent preferred wall damage, and 40% preferred roof damage. These preferences do not align with engineering knowledge of safe housing, which indicates that roof damage is less catastrophic and poses a lesser threat to human safety.

To understand why these preferences and, thus, the misalignment exist, we also asked respondents why they would prefer one type of damage to another. Some respondents provided more than one reason for their preferred failure mode, while other respondents did not answer; therefore, we analyzed relative frequencies shown in Table 5 based on the number of responses (98).

Five reasons for preferring one type of damage to another emerged. The most common reason for preferring wall damage to roof damage was that the roof would still provide shelter from the elements, such as sun and rain if the walls were damaged. This sentiment is best summed up by a man from Tolosa, who explained: *"Because at least you are safe in the rain. You have a shelter. Unlike if there is no roof, but you have walls, you don't have a shelter. During sunny and rainy days, you are not safe."* Thus, the prevailing perception was that if the walls were damaged, this damage would be limited to the wall panels, and the house would remain standing. Even if damaged, the walls could still support the roof and provide shelter for occupants.

However, engineering assessments suggest otherwise. For example, in houses with plywood walls, an estimated 50% of the lateral capacity of the wall frame comes from the plywood sheathing. Therefore, damage to sheathing greatly reduces the capacity of the structure to resist lateral wind loads. Additionally, in houses with gravity load-bearing walls, if the wall panels were to fail, the rest of the house is expected to collapse. Two communities in this study had concrete or masonry gravity load-bearing walls, which are less common in the Philippines than infilled walls in reinforced concrete frames. In infill frame systems, wall damage could occur without major consequences. In the two communities with gravity load-bearing walls, Linao and Tolosa, 50% of respondents preferred roof damage, and the other 50% preferred wall damage. These percentages illustrate that these households are likely not familiar with the housing load paths or what the consequences of damage to load-bearing walls would be for the rest of their house.

Table 5
Relative frequency of responses to "Why would you prefer this type of damage?"

Reason for preference	Prefer wall damage	Prefer roof damage
Shelter from the elements	64%	2%
Can be repaired	31%	78%
Can cause more damage	3%	5%
Cost	2%	5%
Privacy	0%	10%
	n = 58	n = 40

The second most common reason stated for preferring wall damage was that walls were easier to repair than roofs. As a woman in Sagasumbut told us, "*We can just use other materials as a temporary wall*." Many respondents felt that using other materials, such as curtains or tarps, to cover the walls quickly was an easy repair. Additionally, walls were easier to access, and thus, repair, compared to roofs in taller, two-story houses. A woman in Tolosa shared, "I*f the walls are damaged, then they are easier to rebuild than the roof. The walls are just down here, while if the roof* is *damaged, it is more difficult for me to go up there*."

However, ease of repairability was also the most common reason people would rather their roof be damaged. Respondents indicated that the roof could be "*fixed right away*"; whereas, repairing the wall would require more work. As a man from Tolosa explained, "*The roof is easier to replace compared to the walls. You would have to replace more parts if the walls come down."* Also, temporary fixes, such as plastic sheets could be used for the roof, as shared by a woman in Sagasumbut: "*The roof could be easily replaced with tarpaulin, whereas the walls could not."*

The second most common reason that people preferred their walls to not be damaged was for privacy, so "*that you will not be seen when you sleep."* Having the walls remain intact provides a barrier between the occupants and the surrounding neighbors.

A woman in Sagasumbut was the only respondent who captured the goal of the engineering assessments (i.e., to prevent collapse of the house by having roof panel loss be the governing failure). She said that she wanted her walls to remain intact "*because the roof will collapse if we don't have walls."* This response is reflective of a perspective that is concerned with how the performance of one component can affect the performance of other components.

5.3. Modifications to improve housing safety

To understand households' perceptions of how to improve housing safety in typhoons, we asked respondents: "What have you done (or would you do) to make your house safer in a typhoon?" Approximately 30% of respondents did not know or would not do anything; we excluded those answers. Others had more than one response, and we coded all of their responses. Three categories of modifications emerged: strengthening the roof, strengthening the walls, and making additions to the house. Fig. 5 illustrates the coding tree and relative frequencies for modifications to improve housing safety.

5.3.1. Strengthening the roof

As discussed above, respondents expected the roof panels to fail first most often; therefore, it is unsurprising that a majority of modifications to make houses safer focus on improving the strength of the roof (67%). Five modifications to strengthen the roof were present in the responses: tying the roof to the ground or another structure (26%), adding more fasteners to connect the panels to the purlins (21%), adding weight to the roof (9%), replacing the panels with thicker sheets (8%), and changing a wooden truss roof to a flat, concrete slab roof (3%).

Tying the roof and adding weight both improve roof performance by increasing the dead load or downward force on the roof, counteracting wind's uplift force. Our reconnaissance and engineering assessments [9, 41] showed that these ties kept the roof panels attached to the houses in

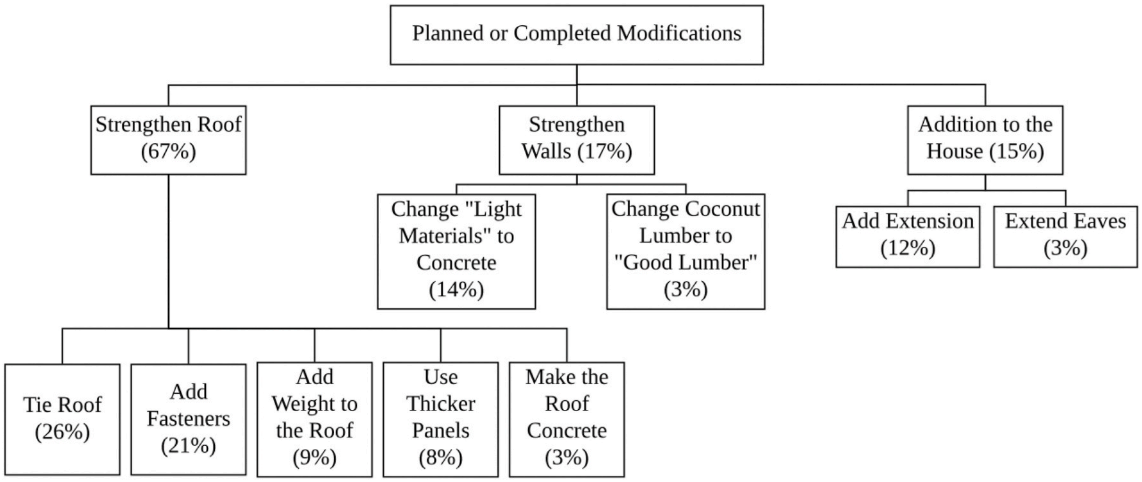

Fig. 5. Coding tree of planned or completed modifications to improve housing safety for 184 responses. The percentage listed indicates the relative frequency of responses, which are summative for parent nodes.

Caputian during Typhoon Ursula. Respondents had used these two strategies before and found them to be effective in securing the roof panels. A woman in Tolosa told us that her family would

> "put heavy things on our roof to prevent it from detaching … the house there [where she previously lived] was made of wood, so to strengthen the structure, we put heavy things on top … yes, it was [effective] because our roofs didn't fly off. It provided additional safety. That's what my father and even my brother used to do."

Other solutions to improve roof performance include adding more fasteners and increasing the thickness of the panels. Both modifications are aligned with engineering assessments, for we found that decreasing the spacing between fasteners (i.e., adding more fasteners) and increasing the panel thickness can improve wind performance of a roof, on average, by 41% and 28%, respectively [9,41].

5.3.2. *Strengthening the walls*

Strengthening the walls was another commonly suggested modification and involved either changing the walls from a wooden frame to a concrete frame with concrete or masonry walls (mentioned in 14% of responses) or changing coconut lumber frames into "good" lumber (mentioned in 3% of responses). Even if households did not plan to change the materials of their house to concrete, most believed that a concrete house is safer in a typhoon. People also recognized that concrete could be more dangerous in an earthquake, which is why we believe very few people wanted concrete roofs. For example, a woman in San Pablo was worried about having a concrete roof: "*If concrete fell onto you, you cannot get up anymore. Not like this one [wood roof]. If it falls on you, you still can get up because it is only made from wood.*" Nevertheless, people preferred concrete walls because they perceived they could stay in a concrete house during a typhoon rather than evacuate, which they felt to be very important. This sentiment arose many times in the interviews. For instance, a woman in Sohoton said, "*Make it [the walls] concrete so that during typhoons we won't have to evacuate anymore*"; another indicated: "*I want it [the walls]to be concrete so that if there is a calamity we would not have to evacuate anymore.*"

Respondents' views of concrete being a safer material is aligned with the engineering assessments; however, the safety of concrete is based on how it is constructed, including factors such as quantity/arrangement of reinforcement and concrete quality., and not merely its presence. One man in Linao explained variation in concrete quality: "*This is class A [the better mixture]: 1 bag of cement, 2 bags of sand, and 3 bags of gravel. Class B is 1 bag of cement, 4 bags sand, and 5 bags gravel,*" and a man in San Pablo thought concrete houses in another location were not safe because they lacked reinforcement: "*For example, those relocation houses in the north are not that strong. They don't even have steel bars.*" However, most respondents did not provide these qualifications.

Those who wanted to change coconut lumber to "good lumber" did so because they perceived coconut lumber to be a poor material. One woman living in a coconut lumber house told us: "*I would like the posts [the columns] to be good lumber, not coco lumber [because] the coco lumber is too young. It gets easily damaged when everybody* is *inside the house. The tendency of the floor is to shake.*" People described coconut lumber as "young," "soft," and prone to rotting and termites, and our reconnaissance revealed that columns made of coconut lumber had deteriorated considerably in the five years since being constructed [9,41]. "Good" lumber refers to different wood species that are harder, older, and less prone to deterioration. One woman in Caputian described her preference for "good" lumber:

> "[In their previous house] We used good lumber, unlike this one [the current house]. We did not use coco lumber because good lumber is forever unlike coconut. The termites are eating the wood [coconut lumber]. We have plenty of termites here in [Caputian]. We paint the wood black so that the termites will not eat the wood and to protect the wood."

Most people did not describe a specific wood species when discussing "good" lumber, but everyone perceived it to be stronger and safer than coconut lumber. In fact, one woman in Sohoton described how she persuaded the organization building her house to use "good" lumber instead of coconut lumber: "*But I told them, 'Ma'am, can we have good lumber instead?' Because I know that coconut lumber does not last that long. It gets damaged easily. Good lumber* is *stronger …*"

5.3.3. *Making additions to the house*

Making additions to the house, which include adding an extension to the front or back of the house and extending the length of the eaves, was mentioned in 15% of responses. Responses were coded to this category when they indicated that extensions would increase the safety of their house. For instance, a man in Caputian added an extension "*to give more protection or strengthen the house more against typhoons.*" Organizations told households that extensions could help make the house safer, as a woman in Tolosa shared: "*They [the organization who built the house] said that if we put an extension in the front and back area of the house, we will be safer since the extension will shield the strong wind.*" Additionally, some respondents shared that this strategy was based upon their observations from past typhoons. Two respondents told us that a reason other houses collapsed in Typhoon Ursula was "*because those houses have no* *extensions*."

While most respondents saw extensions as modifications that would improve wind performance, engineering assessments indicate that extensions could either improve or worsen performance. In one community, extensions provided much needed lateral resistance that improved wind performance [9,41]; however, based on the house design, some extensions may increase wind loads by changing the house geometry. We cannot say whether the preference for adding extensions is aligned or misaligned with the engineering assessments, but it does show that some respondents are thinking with a systems perspective of how modifications to one housing component may affect the rest of the house.

Notably, another reason for extensions was protection against the elements. Nearly every respondent mentioned a concern of water getting into their house when it rained. A few households said they would lengthen the eaves of their roof to protect against the rain. For instance, a man in Linao said "*I will buy wider flat sheets [for roof panels] because the sheets that they [the implementing organization] used were very short. The tendency if there is heavy rain is that the rain gets inside the house, and it causes leaks.*" This is a misalignment with engineering assessments because extending the eaves of a house increases the likelihood of roof panel loss due to increased uplift wind forces on the panels. As found in the engineering assessments, adding a 0.5 and 1.0-m-long eave decreases wind performance by 10% and 25% in terms of the wind speed that can be resisted without failure, respectively, compared to a house with no eaves [9,41]. None of the respondents mentioned that rain protection might worsen wind performance.

6. Discussion

Schilderman and Lyons [47] state that post-disaster "reconstruction [programs] can build on the strengths, but has to address the weaknesses [of construction capacity]" (p. 221). In the context of this study, addressing weaknesses means improving households' understanding of houses as systems. Many of the household perceptions of safe housing discussed above align with engineering assessments of safe housing when we focus on individual components. However, when we think about the house as a system of components that work together, we find misalignments between household perceptions and engineering assessments.

A majority of respondents' expected failure mode was roof panel loss, which generally agrees with the engineering assessments. This alignment is critical because households are most likely to modify the component they expect to be the most damaged or damaged first. This alignment is further apparent in respondents' plans to improve the performance of the roof by adding fasteners, ties, weight, or thicker CGI panels. Indeed, individually, all of the suggested modifications, except for lengthening the eaves and adding extensions, are likely to improve the performance of roof components.

However, the systems' perspective of a house is mostly absent in local knowledge. For example, when we think about the effect these modifications will have on other components of the house, there is a gap between household perceptions and engineering assessments. While using thicker panels and adding fasteners would improve panel performance, these changes could also increase the risk of damage to the walls and, thus, the entire house. When a panel is removed from the house, the demand on other components is lessened. If, instead, the panels do not detach, then greater demand is propagated to the walls, which might not have sufficient capacity to resist the increased demand. This could lead to catastrophic wall failure, as we observed in the Caputian houses during Typhoon Ursula. When respondents think about strengthening the roof of their house, they also need to ensure that the walls are strong enough to resist an increased demand; however, no households discussed the relationship between these two modifications.

A significant reason that the walls could be unable to resist increased demand is because they lack adequate bracing members or strong connections between the beams and columns. While respondents expected that replacing coconut lumber with a stronger, "good" lumber would make their houses safer, this is likely not the most effective change. In cases where the lumber has deteriorated, especially at connections, replacing these damaged members is undoubtedly important. However, failure or breaking of wood members was not a governing failure mode from the engineering assessments, so changing the wood members to a stronger material is not expected to make a considerable improvement to performance. Instead, adding bracing members and strengthening the connections between wall members will better improve the lateral capacity and performance of the walls, but households did not mention these modifications in discussions of how they would strengthen their house.

Additionally, households' preferred failure mode does not align with the failure mode from the engineering assessments that best meets the performance objectives of minimizing damage and protecting occupant safety. From an engineering perspective, roof panel loss is the failure mode that best meets these objectives. However, most of the respondents who were asked to choose between wall and roof damage stated that they would rather their walls be damaged, mainly because they thought they would still be able to seek shelter under their roof. This suggests that respondents expect that damage to the wall sheathing (e.g., plywood or amakan) would not affect the ability of the system to hold up the structure when, in fact, this damage could compromise the entire structure.

These findings also revealed areas where organizations' knowledge was misaligned with engineering assessments. Importantly, households discussed the poor performance of the amakan material that has been promoted by organizations who believed it would perform well in the wind by blowing out and saving the structure. However, households noted amakan's poor water resistance, and there were major failures of the amakan houses due to insufficient wall-frame strength in Typhoon Ursula. By understanding the local material preferences and knowledge of safe housing and how local knowledge was misaligned with engineering assessments, we were able to highlight the need for more systems discussion in post-disaster housing programs and changes to commonly used materials.

7. Limitations

This study focused on the alignments and misalignments between household perceptions and engineering assessments of houses' roof and wall systems in typhoons' winds. We posit that there are additional housing components and design details in which there are important misalignments between local knowledge and engineering assessments, such as foundation systems and openings (i.e., windows and doors), and recommend that future studies continue to investigate this topic in other contexts, in different hazards, including flooding and storm surge in typhoons, and for different housing designs.

Households in this study received a house directly from implementing organizations and generally did not provide input into the design of their house; thus, we assessed their understanding of safe housing through their responses to interview questions rather than observing their design and construction decisions. Future work should strive to observe households' decision-making processes and include households that self-recover following disasters, for those households are responsible for the design and construction of their house.

In addition, previous studies of risk perceptions have noted differences in the perceptions of men and women. While more women were interviewed in our study, we did not find significant differences in either expected or preferred failure mode or planned modifications between men and women. This work also focused solely on wind hazards. Many people live in multi-hazard environments, including the Philippines, and we recommend expanding this work to encompass multiple hazards, especially given that designs and materials perform differently depending on hazard type.

Additionally, we suggest that future work explore the effectiveness of various risk communication and programming strategies on integrating local knowledge and engineering assessments to address misalignments between the two bodies of knowledge.

8. Conclusions

In this study, we compared household perceptions and engineering assessments of housing safety in future typhoons to identify where they align and misalign, focusing specifically on wind performance of roof and wall systems. We used households' expected failure mode, preferred failure mode, and planned modifications to improve housing safety in typhoons, as reported in interviews, to represent local knowledge. Engineering assessments of the governing failure mode, failure modes that best meet performance objectives, and the effect of design changes for wind performance represented scientific knowledge. We compared these two bodies of knowledge to identify where they align and misalign in six communities affected by Typhoon Yolanda in the Philippines.

The study found that what households understand to be safe is generally well-aligned with engineering assessments when focusing on single components. Roof panel loss was households' most expected failure, which generally agrees with the engineering assessments. Modifications households would make to improve the safety of their roof also align with modifications that would enhance performance in engineering assessments.

While perceptions and assessments are well-aligned at the component level, they are often misaligned when considering the entire house as a system. Housing components are connected, and housing safety depends on their interaction. This understanding was largely missing from households' perceptions. For example, a majority of the households would prefer their walls to be damaged instead of their roof because they would still be able to take shelter from the rain or sun if their roof was intact. Households widely assumed that wall damage would be limited to the wall panels and any damage to the wall panels would not affect the stability of the wall frame and overall structure. Engineering assessments, however, found that the wall panels provided important capacity, not just privacy, and if the walls are damaged, the structure is more likely to collapse or become uninhabitable. Furthermore, households' plans to improve the roof strength could increase wall damage, if not done in conjunction with improving wall strength by adding bracing or strengthening connections.

Understanding the local knowledge of safe housing and how local knowledge is misaligned with engineering assessments allows DRR programs to be better tailored to address specific needs to construct safer housing. The method used in this study of comparing household perceptions with engineering assessments can be used in other post-disaster contexts to identify where there is the greatest need for integrating local and scientific knowledge and addressing misalignments. The findings from this study also suggest a missing systems perspective that needs to be integrated into organizations' post-disaster training programs enhancing build back safer messaging campaigns [e.g. Ref. [10,11]] that have developed messages that are focused on individual components. Short videos, infographics, or demonstrations that highlight the systems nature of a house can be shared through social media or displayed in important community spaces, such as recreation centers or hardware stores. Additionally, training programs can discuss how common modifications will affect a structure's overall performance. By including training about how strengthening one housing component affects others and the overall performance of the house, organizations can empower households to improve housing performance and reduce disaster risk.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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