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Origami Housing: An Innovative and Resilient Postdisaster Temporary Emergency Housing Solution

Claudia Calle Müller, S.M.ASCE[1]; and Mohamed ElZomor, Ph.D., M.ASCE[2]

Abstract: Over the last two decades, natural disasters have led to economic losses exceeding $2.97 trillion, causing 1.23 million deaths and affecting over 4 billion people through injuries, housing loss, displacement, and requiring emergency aid. Data have shown that physical, social, and economic inequities significantly contribute to the vulnerability of communities, especially after disasters. Therefore, low-income communities not only endure more severe and long-lasting infrastructure damage but also face over four times as many deaths per disaster. Natural disasters cause prolonged and widespread homelessness, leading to an inevitable temporary housing crisis, further exacerbated by delayed disaster recovery. This study proposes an innovative short-term Origami temporary emergency housing (TEH) solution, providing an equitable and affordable option to swiftly shelter potential victims postdisasters by considering material, construction, and transportation costs. This research aimed to address postdisaster homelessness challenges by: (1) understanding the timeframe for disaster recovery and TEH implementation following a natural disaster; (2) identifying the main challenges, vulnerabilities, and crucial needs faced by low-income communities postdisaster; (3) recognizing the key characteristics for TEH to be an adequate solution postdisaster; and (4) proposing Origami shelter as a solution for the housing crisis that arises postdisaster and validating its feasibility and applicability through surveying engineering, architecture, and construction (EAC) experts from Peru and Puerto Rico, given the frequent exposure and high vulnerability of these regions to natural disasters. The results underscore the need to implement TEH that can be quickly assembled, enabling victims to reside safely and resume normal activities while infrastructure systems and homes are being repaired or rebuilt. **DOI: 10.1061/JAEIED.AEENG-1809**.
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Introduction

Natural disasters result from a combination of natural hazards, including extreme geological, meteorological, or hydrological events, coupled with exposure and vulnerabilities that threaten communities incapable of withstanding and coping with such events (Lindell and Prater 2003). From 1960 to 2019, there were 11,360 global natural disasters where more than 10 people lost their lives and more than 100 individuals were affected (IFRC 2020). In fact, over the last two decades, natural disasters have caused over $2.97 trillion (USD) in economic losses and 1.23 million deaths (Hendriks and Opdyke 2022; UNDRR CRED 2020). These events have affected more than 4.2 billion individuals, causing damage to human health, injuries, income loss, destruction of infrastructure systems, property damage, homelessness, displacement, and reduced availability of essential resources such as food, electricity, and water (FEW) (El-Anwar et al. 2009; Hendriks and Opdyke 2022; UNDRR CRED 2020).

Natural disasters have the potential to (1) cause significant damage to properties and critical infrastructure systems, such as power stations and communication systems crucial for real-time information transfer and disaster management, hospitals critical for supplying health services to victims, and transportation systems, including roads and bridges, key for facilitating rescue operations; (2) have a significant impact on the economy of countries and communities, resulting in substantial economic losses not only due to damage to infrastructure systems and property but also as a consequence of power outages, evacuation expenses, debris removal, and disruption to business operations; (3) pose threats to people's lives and overall well-being through injuries, adverse effects on human health, loss of income, reduced access to essential resources such as FEW, housing displacement, and, most importantly, the loss of human lives (Calle Müller et al. 2023; He et al. 2021; Hendriks and Opdyke 2022; Shahzad et al. 2022; Shapira et al. 2015; Marchigiani et al. 2013; UNDRR CRED 2020; Urlainis et al. 2022). As such, natural disasters not only stand as the primary source of destruction to our infrastructure systems and buildings, particularly in underdeveloped communities, but also serve as a major hindrance to sustainable development by obstructing social and economic progress (Calle Müller et al. 2023; Hendriks and Opdyke 2022; Shahzad et al. 2022).

Even though natural disasters pose a threat to numerous countries and communities, the resulting losses and damages are not equally distributed. This is largely due to the fact that developing countries are often more vulnerable to these disasters. Inequities in physical, social, and economic conditions significantly contribute to the vulnerability of these communities (Dhakal et al. 2022; Llorente-Marrón et al. 2020; Shapira et al. 2015). Low-income communities not only frequently lack education, income, and resources needed to prevent, prepare for, and adequately respond to natural disasters but are also more exposed and highly vulnerable to them (Dhakal et al. 2022; IFRC 2020; Masozera et al. 2007). In fact, on average, low-income countries have more than four times as many deaths per disaster as high-income countries and experience more severe and long-lasting infrastructure damage due to

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poor infrastructure design and construction, along with the inevitable collapse of buildings (Hausler 2010; Hendriks and Opdyke 2022; Kenny 2009; Mastroianni et al. 2021). This results in prolonged and widespread homelessness, health issues, and a housing crisis, which is frequently already present in low-income communities but is greatly exacerbated by natural disasters. Furthermore, low-income communities often receive delayed disaster recovery, including delivering critical supplies, and implementing emergency housing and emergency relief can take several months or even years (Huang et al. 2022; Rendon et al. 2021). This not only aggravates even more the housing and health crisis but could also lead to fatalities, heightened levels of distress, and suffering (Huang et al. 2022).

A home is a basic human need and is essential to the quality of life and overall well-being of individuals and communities (Barakat 2003; Costanza et al. 2007). As such, temporary homes play a key role in supporting the three sustainability pillars, including the economic, social, and environmental dimensions (Hosseini et al. 2020). A temporary home offers basic living conditions, aiding those affected by a natural disaster in coping and facilitating a sustainable transition to routine activities while infrastructure systems and homes are repaired or rebuilt (Félix et al. 2020; Soleimani and Matini 2022). Temporary shelters should be resilient and able to withstand climate and environmental challenges, including extreme temperatures, high winds, severe rainfall, as well as natural disasters and earthquake's aftershocks (Bannova and Nystrom 2015; Domingos and Rato 2019; Rahat et al. 2023). Most importantly, shelters should provide individuals with a safe, livable, comfortable, and resilient shelter to live and function (Ihuah et al. 2014). Furthermore, pursuing a sustainable shelter alternative is crucial for two primary reasons: (1) the growing environmental challenges and concerns, as well as the enormous environmental footprint of the built environment that causes significant environmental impacts (Beatini et al. 2023; Chau et al. 2015; Domingos and Rato 2019; Lu et al. 2020; Maciejewska et al. 2022; United Nations Environment Programme 2009; Wei et al. 2016); and (2) the criticism directed at temporary emergency housing (TEH) due to social, economic, and environmental concerns (Arslan and Cosgun 2008; Atmaca 2017; El-Anwar et al. 2009; Félix et al. 2013, 2020; Hosseini et al. 2020; Johnson 2007). With that said, providing an immediate, quick, easy-to-assembly, resilient, equitable, affordable, and sustainable TEH solution to ensure all victims have a shelter after a natural disaster is of the utmost importance (Beatini et al. 2023; Johnson 2007; Rahat et al. 2023; Rendon et al. 2021; Shahzad et al. 2022).

Providing TEH is crucial for the quick recovery of individuals and communities, enabling safe rebuilding (Johnson 2007). It plays a crucial role in reestablishing a sense of normalcy in the affected community while also preventing an increase in mortality rates and the spread of diseases. Furthermore, TEH offers protection against external factors such as adverse weather conditions, ensures privacy, and contributes to improved health conditions (Félix et al. 2013). As such, TEH should be readily accessible and available following a natural disaster (Arslan and Cosgun 2008; Johnson 2007). To achieve this, shelters should not only be easy and quick to construct but also lightweight and deployable to facilitate their transport to affected areas. Furthermore, shelters need to be affordable, with costs proportionate to the intended duration of use, as well as easily removable, transferrable, adaptable, or recyclable once they are no longer needed (Arslan and Cosgun 2008; Félix et al. 2013; Johnson 2007). To this end, it is crucial to explore infrastructure technology and innovative construction methods with the following objectives: (1) improving infrastructure resilience and sustainability; (2) ensuring efficiency and functionality; (3) ensuring cost-effectiveness by considering material, construction, and transportation costs, and reusability; and (4) facilitating transportation given that access may be challenging or limited following a natural disaster (Bannova and Nystrom 2015; Criswell and Carlson 2004; Hong Park 2021).

The ancient art of folding paper, known as Origami, offers an innovative and effective means of addressing and solving diverse engineering problems, including those associated with construction, assembly, and transportation, particularly during challenging times, including after natural disasters. Origami structures are geometrically versatile, adaptable, flexible, and can be easily and quickly assembled (Filipov et al. 2015). Furthermore, Origami's distinctive capability to convert flat or compactly stored systems into adaptable, versatile three-dimensional structures enhances their functionality, making it a valuable tool for tackling engineering challenges that arise postdisaster (Dudte et al. 2016; Filipov et al. 2015; Hartl et al. 2012; Li et al. 2019; Meloni et al. 2021). In fact, Origami is rapidly emerging in science, engineering, and construction applications as dynamic, deployable, adaptable, functional, and reconfigurable engineering systems of all scales that can be fabricated with a wide variety of materials and methods (Filipov et al. 2015; Del Grosso and Basso 2010), thus highlighting the great potential of Origami to provide quick and affordable temporary emergency shelters for victims after a natural disaster. Despite its potential, this innovative solution remains understudied. This study aims to fill this gap by proposing Origami as an economic solution, which addresses the problem of homelessness that arises postdisaster and exposes victims to health issues, displacements, and other social threats (Araya et al. 2019; Hendriks and Opdyke 2022). Origami TEH is a short-term solution that provides a quick, safe, and livable place for victims.

The proposed Origami compact foldable shelters are made of white polypropylene. Products of this material have a 20-year lifetime, thus allowing Origami temporary housing to be reusable, transferable, and recycled by mechanical processes (Mannheim and Simenfalvi 2020). The shelters can be unfolded and folded like Origami to be assembled and disassembled, respectively. Each unit weighs only 35 pounds, and when collapsed, each unit measures $79 \times 40 \times 2.75$ in. (Burck et al. 2015; Home Harmonizing n.d.). Thus, several units can be stacked together, allowing for easy storage and transportation. When fully erected, each shelter measures $6.5 \times 6.5 \times 6.5$ ft and can accommodate two adults and two children for sleeping (Burck et al. 2015; Home Harmonizing n.d.). To accommodate larger families, individual units can be combined to create larger dwellings. Their lightness allows them to be easily carried by an individual, and their effortless assembly takes only about 2 min. All the aforementioned features reflect the practicality and optimality of the proposed solution as a temporary emergency shelter postdisaster.

To evaluate the feasibility of the proposed Origami shelters, this study surveyed community stakeholders, including experts in the civil engineering field, architects, and other professionals. To meet the objectives of the study, Peru and Puerto Rico were chosen as the regions of focus since they are frequently exposed to natural disasters and are highly vulnerable to them, given their limited financial resources, significant levels of poverty, and informal construction.

Background

An equitable distribution of resources is crucial to reducing the vulnerability of communities (Miller and Vela 2014). Nonetheless, low-income communities often struggle with resource scarcity

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while facing more immediate threats such as unemployment, lack of livelihood opportunities, and food insecurity (Degg and Chester 2005; Maskrey 1989). These circumstances often lead to informal construction and precarious and vulnerable living conditions. As a result, these communities experience heightened and long-lasting infrastructure damage, leading to the inevitable collapse of buildings. This is often attributable to poor infrastructure design and construction and the prevalence of informal construction (Hausler 2010; Hendriks and Opdyke 2022; Kenny 2009; Mastroianni et al. 2021). This results in prolonged and widespread homelessness, health issues, and a housing crisis, which are often preexisting in low-income communities but are exacerbated by natural disasters. Furthermore, low-income communities frequently encounter delays in disaster recovery efforts, with emergency housing and relief taking several months or even years to materialize (Rendon et al. 2021). This aggravates even more the housing and health crisis. Additionally, experiencing a natural disaster depletes resources, particularly in low-income communities, further increasing the likelihood of households remaining in poverty (Miller and Vela 2014; Rosemberg et al. 2010). This, in turn, exacerbates the exposure and vulnerability of low-income communities to future natural disasters, diminishes their coping capacity, and deepens even more the housing crisis.

Conducting surveys in Peru and Puerto Rico can help assess the urgency of TEH after natural disasters as well as the feasibility of the proposed Origami shelter. Peru is a developing country that is highly exposed and extremely vulnerable to earthquakes, given the limited financial resources, economic inequalities, significant poverty levels, and the prevalence of informal construction (Degg and Chester 2005; Glave et al. 2008). This country has experienced significant earthquakes resulting in thousands of fatalities, severe infrastructure damage or collapse, and substantial economic losses (Tinman et al. 2017). For example, the 2007 Pisco earthquake (Mw 8.0) produced enormous destruction. According to the National Institute for Civil Defense of Peru, this earthquake caused 519 deaths, collapsed more than 70,000 houses, and damaged more than 33,000 houses (INDECI 2007; San Bartolomé et al. 2008). Puerto Rico, a developing Caribbean Island within the US territory, is highly susceptible to natural disasters, including earthquakes, hurricanes, severe storms, and flooding [Geological Survey (US) et al. 1996; Goldwyn et al. 2022]. Furthermore, this island is highly vulnerable to such natural disasters due to a combination of constrained financial resources, economic inequalities, high poverty levels, and the prevalence of informal construction (Goldwyn et al. 2022; Talbot et al. 2022). Puerto Rico has experienced severe damage and delayed recovery after diverse natural disasters. For example, the 2017 Maria hurricane resulted in widespread destruction, requiring the reconstruction or repair of approximately 400,000 homes, which represented about one-third of all homes, incurring an estimated $90 billion in damages (Brown 2018; Kishore et al. 2018; Talbot et al. 2022). With that said, surveying in Peru and Puerto Rico can shed light on the challenges faced by developing regions and help assess the urgency of TEH postdisaster and the feasibility of the Origami shelter. These reasons include the following: (1) heightened exposure and vulnerability to natural disasters: both regions have been significantly impacted by catastrophic natural disasters, making them relevant and suitable study contexts for addressing postdisaster challenges; (2) limited financial resources and significant levels of poverty: this socioeconomic context exacerbates the challenges faced by communities in the aftermath of disasters, particularly in terms of housing and homelessness; (3) prevalence of informal construction: this makes the regions more vulnerable to the impacts of natural disasters, leading to increased homelessness and housing insecurity following such events; and (4) sociopolitical factors: these impact the access to recovery funds, the speed of funds dispersal, and the role of external assistance, which add complexity to the postdisaster recovery process [Brown 2018; Degg and Chester 2005; Geological Survey (US) et al. 1996; Glave et al. 2008; Goldwyn et al. 2022; INDECI 2007; Kishore et al. 2018; San Bartolomé et al. 2008; Talbot et al. 2022; Tinman et al. 2017].

Methodology

This study is guided by five research questions: (1) What is the expected timeframe for disaster recovery after a natural disaster, and how long does TEH implementation typically take in both Peru and Puerto Rico? (2) What major challenges, vulnerabilities, and necessities do low-income communities face after a significant natural disaster in Peru and Puerto Rico? (3) To what extent do major challenges, vulnerabilities, and crucial needs differ between Peru and Puerto Rico? (4) What key characteristics are crucial for a temporary emergency shelter to be a viable, equitable, and adequate postdisaster solution? (5) What are the primary challenges associated with using Origami shelters as a TEH solution after a major natural disaster in both Peru and Puerto Rico?

This research addressed these five questions by surveying community stakeholders, including experts in the fields of civil EAC, alongside other relevant professionals in Peru and Puerto Rico, such as those in education, business, finance, and social sciences. Given the frequent exposure and high vulnerability of these regions to various natural disasters, these professionals possess extensive knowledge and expertise in natural disasters and their impact on both infrastructure and communities. Additionally, they are equipped with the knowledge and skills necessary to address postdisaster challenges, as EAC education in Peru and Puerto Rico is intricately tailored to address the specific challenges posed by natural disasters. Furthermore, these experts often participate in disaster management efforts and/or advise disaster/emergency managers on how to better prepare and respond to such threats.

The goals of the survey were to (1) understand the current situation of disaster recovery; (2) understand the challenges, vulnerabilities, and critical needs of low-income communities after a natural disaster; (3) evaluate the urgency of implementing emergency shelters postdisaster; (4) identify the most significant characteristics of temporary emergency shelters; (5) evaluate the feasibility of the proposed Origami compact foldable shelters; and (6) understand the primary challenges associated with the utilization of the Origami temporary emergency shelters.

Survey Design

This study used a purposive sampling process to collect data. It refers to a judgmental sampling method in which individuals, i.e., disaster experts, including professionals in the fields of EAC, are selected to be part of the sample based on the researcher's judgment as to which individuals would be the most useful or representative of the entire population. The survey questionnaire was developed using an online tool, Qualtrics. To distribute the survey, two methods were utilized: (1) social media platforms, particularly Facebook groups related to civil engineering and disaster management, where both private and governmental entities operate their official forums and numerous professionals engage in research activities; and (2) emails targeting professors, building officials, engineers, architects, and working professionals within the relevant fields. This study used a mixed-methods sequential explanatory design to collect and analyze both quantitative and qualitative data from experts. The survey was designed considering the data collected from previous literature regarding the key factors, challenges, and critical needs that impact communities in the aftermath of major natural disasters. The administered survey included a demographic section and 13 questions. The initial three questions aimed to identify experts' experience of natural disasters by inquiring about (1) whether they had experienced a major natural disaster; (2) inviting an open-ended response about their experience if they had faced a natural disaster; and (3) whether they had participated in disaster management. The following two questions sought to identify the duration of disaster recovery and the time it takes for all affected individuals to get access to temporary emergency shelters. The next two questions focused on comprehending the challenges, vulnerabilities, and crucial needs of low-income communities postdisaster. The following three questions assessed the significance of investigating TEH and the crucial characteristics that these shelters should possess. The next question asked experts to consider whether TEH could improve the health and well-being of disaster victims. The following question aimed to evaluate the suitability of a compact, foldable Origami shelter as a TEH solution postdisaster. The final question aimed to understand the biggest challenges of the proposed Origami shelter.

This research conducted three statistical metrics to evaluate the consistency, reliability, and adequacy of the sample size. These measures included the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy, the Bartlett test of sphericity, and the Cronbach alpha test (Pradhananga et al. 2022).

KMO Measure

The KMO test serves as a statistical indicator of sampling adequacy for individual variables within the model and for the complete model. The KMO value ranges from 0 to 1, with a value of 0.6 or higher signifying adequacy for sample sizes below 100 (Pradhananga et al. 2022). This test is described by the following equation:

$$\mathrm{KMO}_j = \frac{\sum_{i \neq j} R_{ij}^2}{\sum_{i \neq j} R_{ij}^2 + \sum_{i \neq j} U_{ij}^2}$$

where U_{ij} = partial covariance matrix; and R_{ij} = correlation matrix.

Bartlett's Test of Sphericity

This statistical metric assesses the redundancy between variables. It tests the null hypothesis H_0, which affirms that the variables are orthogonal, meaning they are not correlated. This implies that the original correlation matrix is considered an identity matrix. On the other hand, the alternative hypothesis, H_1, states that the variables are not orthogonal, indicating sufficient correlation and that the correlation matrix deviates significantly from the identity matrix. A significance level below 0.05 indicates the adequacy of the factor analysis (Pradhananga et al. 2022). This test is described by the following equation:

$$\chi^2 = \left(n - 1 - \frac{2p + 5}{6}\right) X \ln |R|$$

where n = total sample size; p = number of variables; and R = correlation matrix.

Cronbach's Alpha Test

This statistical test evaluates the questionnaire's reliability. It is a simple method to determine the reliability of scores, particularly when multiple items measure the same underlying construct. It is a measure of internal consistency that ranges between 0 and 1. A value greater than 0.7 is acceptable (Pradhananga et al. 2022). This test is described by the following equation:

$$\alpha = \frac{n\bar{r}}{1 + \overline{r(n-1)}}$$

where $\bar{r}$ = mean correlation between items; and n = number of items.

Ordered Probit Regression Model

This study utilized statistically ordered probit regression analysis to investigate the impact of different variables on the dependent variable, i.e., whether Origami shelters are an adequate solution for TEH postdisaster. This analytical approach is well-suited for categorical dependent variables and is conducted to determine which independent variable exhibits a statistically significant influence on the dependent variable (Pradhananga et al. 2022, 2023). The ordinal probit regression model uses these parameters through the following equation:

$$y_i^* = X_i\beta + \varepsilon$$

where y_i^* = latent variable measuring whether Origami shelters are an adequate solution for TEH postdisaster for the ith participant; $X_i = (k \times 1)$ vector of observed nonrandom explanatory variables; $\beta = (k \times 1)$ vector of unknown parameters; and error factor (ε) captures the reality that Origami shelters are an adequate solution postdisaster is not perfectly predicted by the regression equation. Therefore, the observed importance of this solution, y_i, is determined from the model according to

$$y_i. = \left\{\begin{array}{l} 1 \ \text{ if } -\infty \leq y_i^* \leq \mu_1 \text{ (Not a good solution)} \\ 2 \text{ if } \mu_1 \leq y_i^* \leq \mu_2 \text{ (Somewhat good)} \\ 3 \ \text{ if } \mu_2 \leq y_i^* \leq \mu_3 \text{ (Good)} \\ 4 \ \text{ if } \mu_3 \leq y_i^* \leq \mu_4 \text{ (Considerably good)} \\ 5 \ \text{ if } \mu_4 \leq y_i^* \leq \mu_5 \text{ (Excellent solution)} \end{array}\right\}$$

In the equation, the partial change in y^* with respect to X_i is β_i units. This signifies that for a unit change in X_i, y^* is expected to change by β_i units, holding all variables constant. Moreover, the significance test utilizes the z-score to describe the expected behavior of the mean for a data sample with a specific number of observations. The P-value reflects the confidence level regarding the correlation between independent variables and the dependent variable. In this study, a confidence interval of 95% was assumed, and the associated z-score was derived as 1.96. This implies that the significance is achieved when alpha is less than or equal to 0.05. Fig. 1 illustrates the research overview.

Results

This section presents the results associated with the responses of 65 experts from Peru and 54 from Puerto Rico in the fields of civil EAC, and others alongside other relevant professionals, such as those in education, business, finance, and social sciences. The recorded sociodemographic data, as depicted in Fig. 2, included a diverse group of Peruvian and Puerto Rican experts. This included (1) 42 males, 19 females, and 4 experts who preferred not to answer from Peru and 31 males, 16 females, 1 nonbinary individual, and 6 who preferred not to answer from Puerto Rico; (2) professionals from diverse educational backgrounds, ranging from bachelor's degrees to doctoral and professional degrees; and (3) experts spanning a range of ages from 18–25 to above 60 years. These professionals have extensive expertise in natural disasters and their impact on both infrastructure and communities, attributed not only to the

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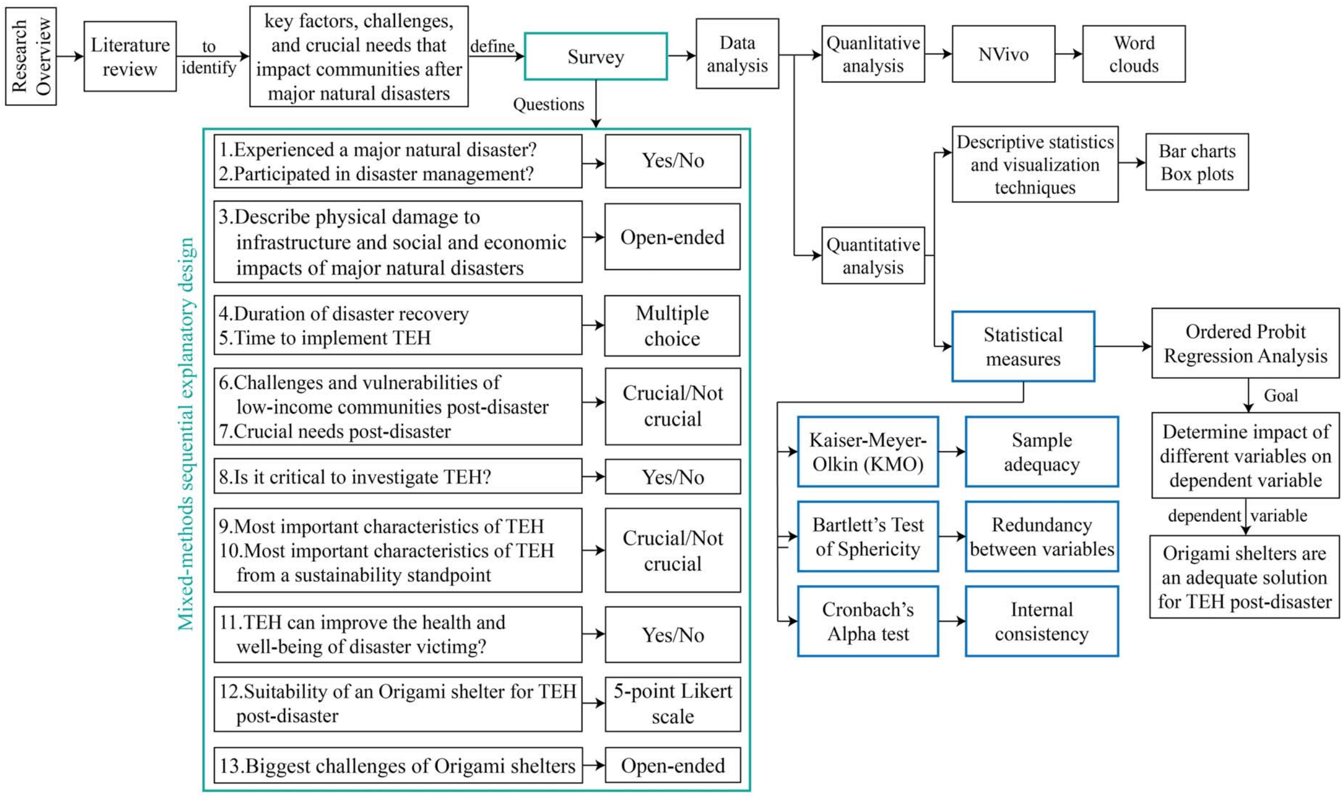

Fig. 1. Research overview.

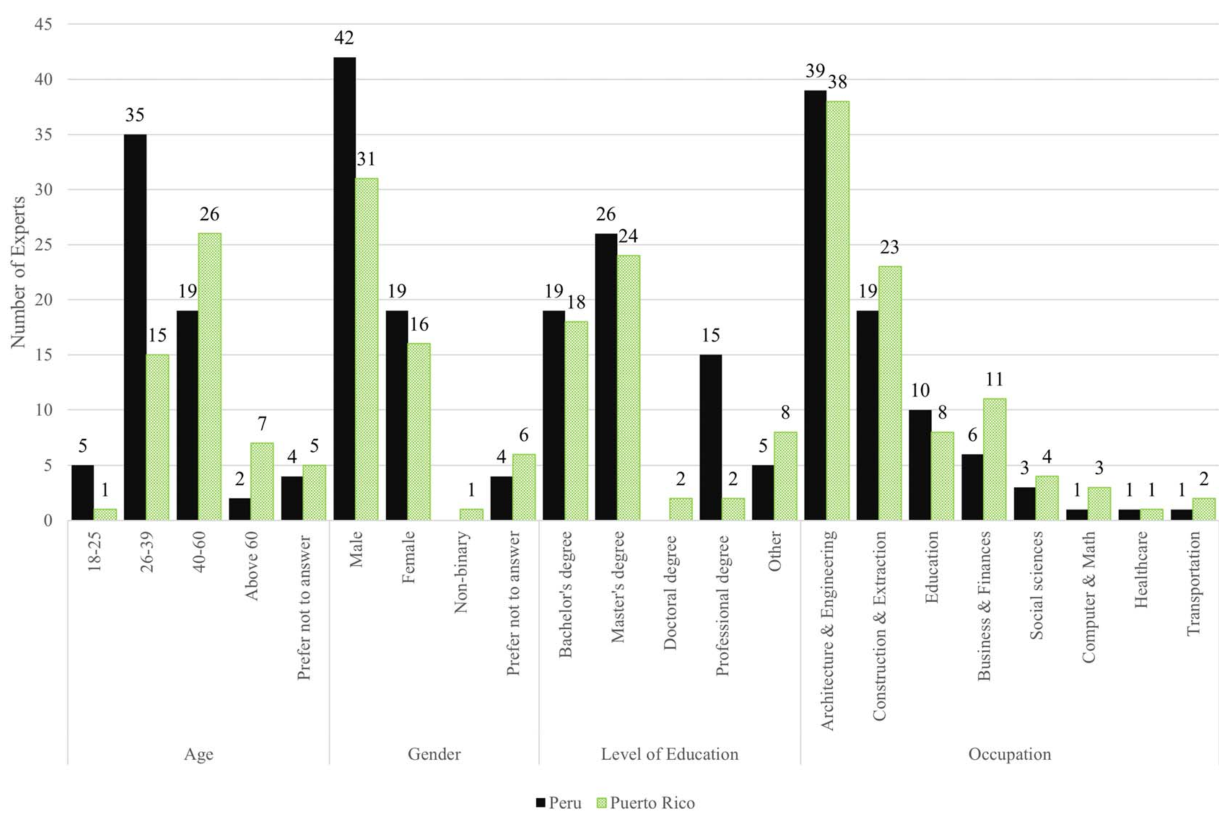

Fig. 2. Sociodemographic background.

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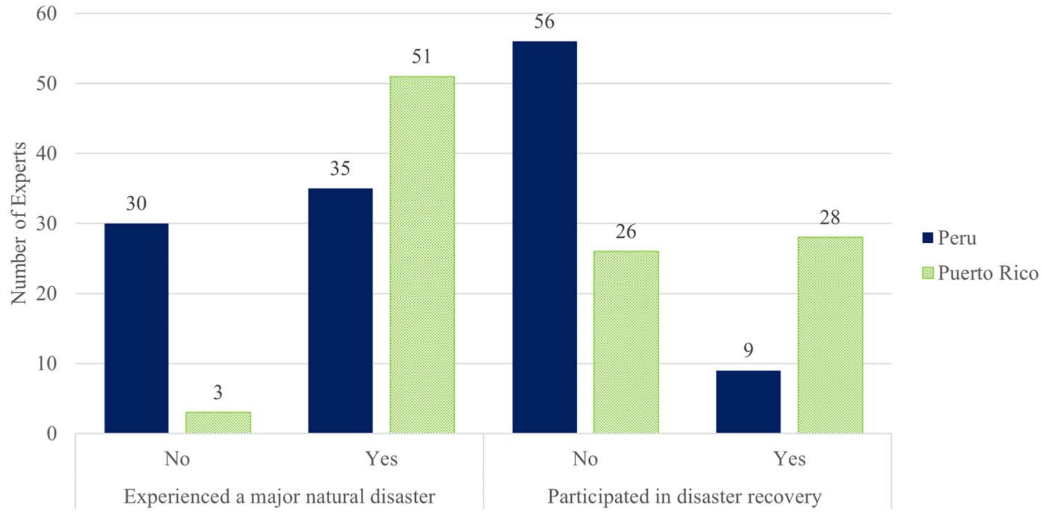

Fig. 3. Experts' experience of natural disasters.

frequent exposure and high vulnerability of these regions to various natural disasters but also to the financial constraints, substantial poverty rates, and prevalence of informal construction in these areas. As a result, EAC education in Peru and Puerto Rico is intricately tailored to address the specific challenges posed by natural disasters.

The first three questions aimed to identify professionals' experience with natural disasters by asking them if they had experienced a major natural disaster and whether they had participated in disaster management. The results of this study, presented in Fig. 3, reveal that (1) among the 65 experts surveyed in Peru, 35 have experienced a major natural disaster, and among 54 experts surveyed in Puerto Rico, 51 have experienced a major natural disaster; and (2) nine professionals from Peru have participated in disaster management and/or recovery in Peru, compared to 28 from Puerto Rico. Furthermore, experts who had experienced a major natural disaster were asked to describe the physical damage to infrastructure and the social and economic impacts on the community caused by the natural disaster. To analyze the experts' insights, the authors used NVIVO. Fig. 4 depicts word cloud representations of word frequency generated from data analysis through NVIVO for Peru and Puerto Rico. The size of words represents the frequency of their usage. For Peru, (1) the words *damage*, *earthquake*, and *homes* had the highest frequency; and (2) the words *infrastructure*, *collapse*, *affected*, *significant*, *destroyed*, *buildings*, *economic*, and *people* also had high frequencies. From Fig. 4(a), it can be inferred that Peru was highly impacted by the 2007 earthquake in Pisco, Ica, experiencing significant economic losses, severe damage, and collapse of infrastructure and buildings. For Puerto Rico, (1) the words *power*, *damage*, *water*, and *loss* had the highest frequency; and (2) the words *lost*, *hurricane*, *roads*, *flooding*, and *months* also had high frequencies. Fig. 4(b) suggests that Puerto Rico is highly affected by hurricanes, leading to flooding, power failures, and severe and long-lasting damage to roads and infrastructure. Furthermore, it can be inferred that Puerto Rico is impacted not only by hurricanes but also by earthquakes.

The following two questions aimed to understand how long disaster recovery takes in Peru and Puerto Rico and how long it takes for all affected individuals to get access to temporary emergency shelters. The recorded data, presented in Fig. 5, showed that (1) around 65% of surveyed Peruvian experts (42 individuals) consider that the recovery period after a major natural disaster in the country exceeds 1 year; and (2) around 60% of surveyed Puerto Rican experts (32 individuals) consider that the recovery period after a major natural disaster on the island surpasses 1 year. Furthermore, Peruvian and Puerto Rican professionals hold varying opinions on the time it takes for all affected individuals and communities to get access to TEH after a major natural disaster, as shown in Fig. 5.

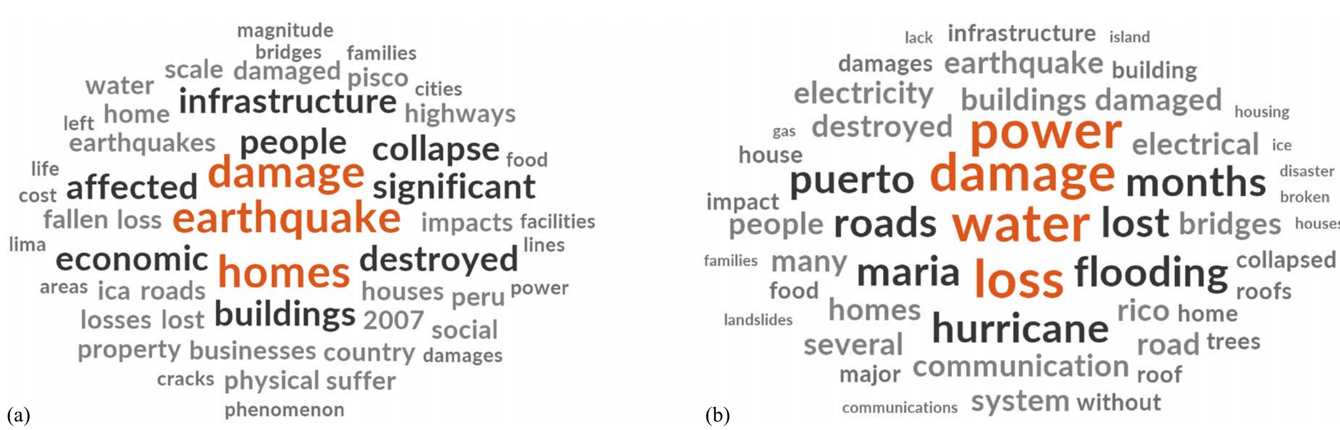

Fig. 4. Word cloud representations of word frequency generated from data analysis through NVIVO based on experts' experiences of natural disasters in (a) Peru; and (b) Puerto Rico.

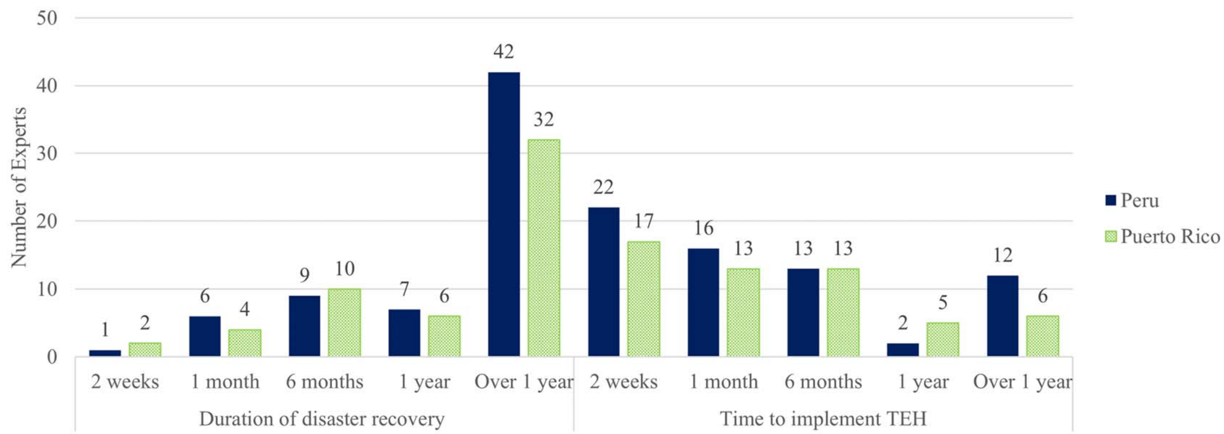

Fig. 5. Experts' opinions related to disaster recovery.

According to this study's results from Peru, (1) around 18% consider that implementing TEH for all victims takes more than 1 year; (2) around 3% consider it takes 1 year; (3) around 20% consider it takes 6 months; (4) around 25% think it takes 1 month; and (5) around 34% consider it takes 2 weeks. On the other hand, according to the study's results from Puerto Rico, (1) around 11% consider that implementing TEH for all victims takes more than 1 year; (2) around 9% consider it takes 1 year; (3) around 24% consider it takes 6 months; (4) around 24% think it takes 1 month; and (5) around 32% consider it takes 2 weeks.

Fig. 6 highlights the importance of investigating TEH as a post-disaster solution, with nearly all surveyed experts, except one from each region, expressing its critical importance. Furthermore, as shown in Fig. 6, 55 out of 65 Peruvian experts from Peru and 47 out of 54 Puerto Rican experts consider that TEH could potentially improve victim's health and well-being (i.e., reduce stress, anxiety, and/or depression; give a sense of security and support; and rebuild self-esteem and provide hope). Finally, Fig. 6 also presents the suitability of an Origami shelter for TEH postdisaster. The results show that (1) around 48% of Peruvian experts and 52% of Puerto Rican experts consider Origami shelter an excellent solution; (2) around 32% of Peruvian experts and around 15% of Puerto Rican experts consider it a very good solution; and (3) less than 5% of Peruvian experts and less than 6% of Puerto Rican experts consider it a slightly good or not good solution.

The following question aimed to understand the biggest challenges of the proposed Origami shelter. The results are presented in box plots, where the box ranges from the first quartile (Q1) to the third quartile (Q3) of the distribution, the median is indicated by a horizontal line, the mean is represented with an "x," and the whiskers highlight the minimum and maximum values. As evident from the box plots for Peru shown in Fig. 7, the biggest challenges of the proposed solution for Peru include: (1) connection with FEW, yielding a mean of 4.33; (2) structure of the shelter, i.e., being able to face earthquake aftershocks and sustainable winds, reflecting a mean of 4.2; (3) dependency on the support of governments, countries, and all entities involved in the recovery process of communities, yielding a mean of 3.98; and (4) transportation to the needed location, reflecting a mean of 3.89. Fig. 8 presents the box plots for Puerto Rico. As evident from these box plots, the biggest challenges of the proposed solution for Puerto Rico include: (1) connection with FEW, yielding a mean of 4.48; (2) construction of shelters, reflecting a mean of 4.19; (3) structure of the shelter, i.e., being able to face earthquake aftershocks and sustainable winds, reflecting a mean of 4.17; and (4) transportation to the needed location, yielding a mean of 4.13.

This study used several statistical metrics, including KMO, Bartlett's test of sphericity, and Cronbach's alpha, to evaluate the consistency, reliability, and adequacy of the data sample sizes from both Peru and Puerto Rico using SPSS. The KMO values obtained were 0.728 for the Peruvian sample and 0.639 for the Puerto Rican sample, both exceeding the threshold of 0.6, indicating the adequacy of the sample sizes. The calculated Cronbach's alpha values were 0.864 for Peru and 0.859 for Puerto Rico. These values are greater than 0.7, demonstrating the reliability of the sample sizes. Finally, Bartlett's test of sphericity tested the adequacy of the correlation between the variables. The obtained significance levels

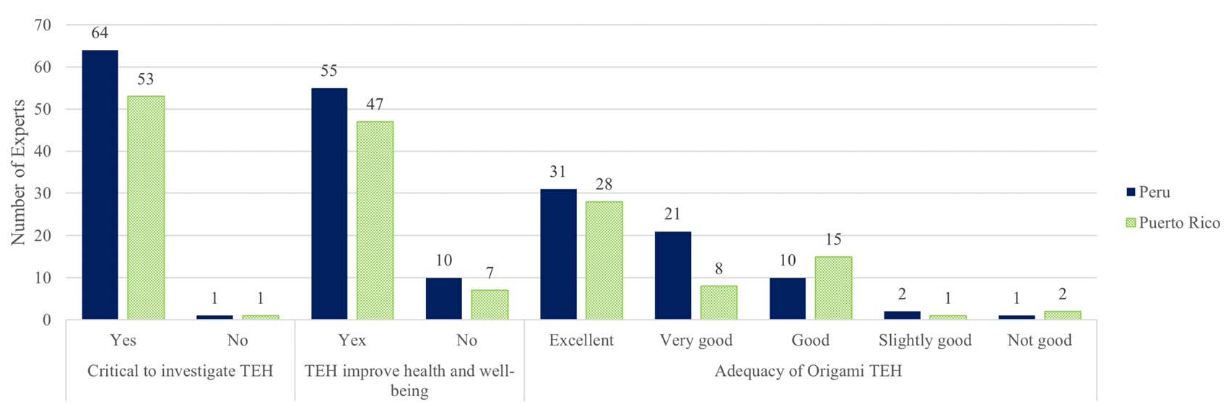

Fig. 6. Experts' opinions related to TEH.

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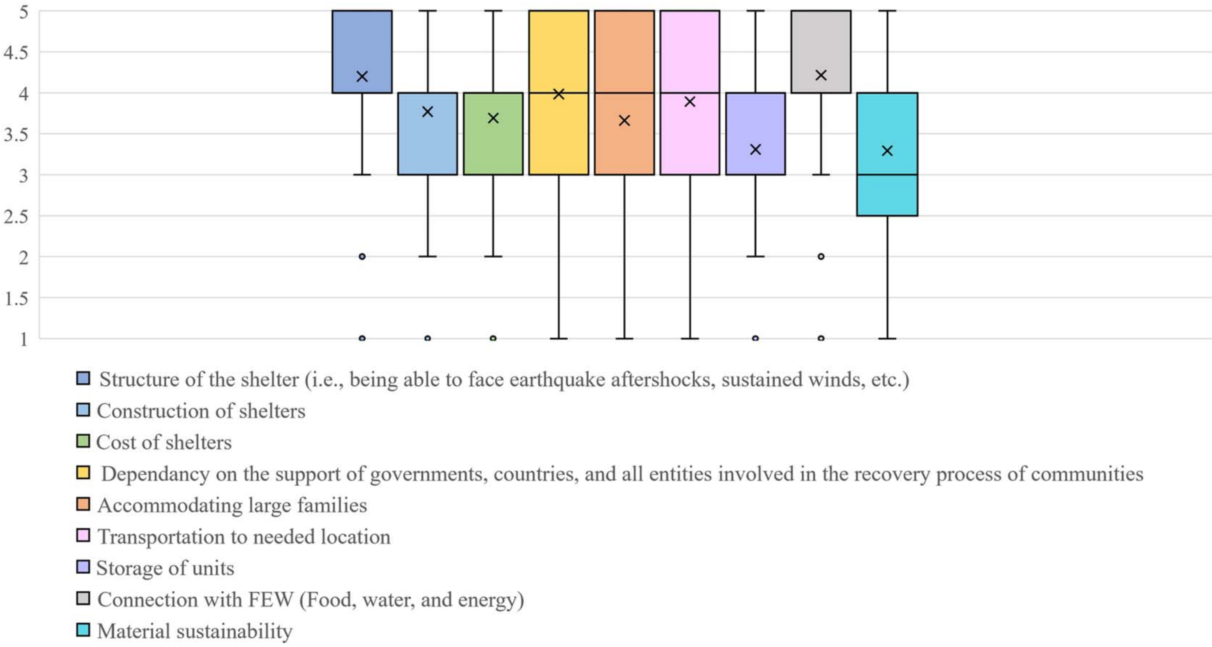

Fig. 7. Biggest challenges of the proposed solution in Peru.

were less than 0.001 for both samples, indicating that the variables are not orthogonal.

Ordered Probit Regression Analysis

The ordered probit regression model addresses this study's research questions regarding the major challenges, vulnerabilities, and crucial needs that low-income communities face after a major natural disaster, as well as the most important features that a temporary emergency shelter should have to be an adequate solution postdisaster.

Table 1 presents the results of the ordered probit regression model evaluating the suitability of Origami shelters as a postdisaster TEH solution postdisaster for Peru, with a pseudo-R^2 value of 0.4073. Several variables exhibit p-values equal to or below 0.05, such as (1) lack of housing/shelter is a critical challenge; (2) lack of water and/or food is a critical challenge; (3) feeling unsafe is a critical challenge; (4) delayed disaster recovery is a critical challenge; (5) having a shelter is a crucial need; (6) easy assembly is a crucial feature for TEH; (7) lightweight is a crucial feature for TEH; (8) readily availability is crucial for TEH; (9) easy storage of units is crucial for TEH; (10) large production capacity is crucial for TEH; (11) reusability is crucial for TEH; (12) transferability is crucial for TEH; and (13) easy disassembly is crucial for TEH. Consequently, it can be inferred that the data hold statistical significance, supporting the hypothesis regarding the true relationship between the dependent variable (i.e., whether Origami shelters are an adequate TEH solution postdisaster) and the independent variables.

In Table 1, μ_1, μ_2, μ_3, and μ_4 are the coefficients of the ordered probit model with the values of −1.35, −0.77, 0.58, and 2.41, respectively. These coefficients signify thresholds, representing the predicted cumulative probabilities at covariate values of zero. Finally, the results obtained from the regression analysis indicate that several variables significantly contribute to the adequacy of Origami shelters as a postdisaster TEH solution, including (1) critical challenges such as lack of housing/shelter ($\beta = -3.99$), lack of water and food ($\beta = -3.72$), feeling unsafe ($\beta = 1.93$), delayed disaster recovery ($\beta = 1.24$); (2) the crucial need of having a shelter postdisaster ($\beta = 3.75$); and (3) crucial features required in a TEH, such as ease of assembly ($\beta = 1.64$); lightness ($\beta = -2.25$), availability ($\beta = 2.67$), ease of storage ($\beta = -3.24$), high production capacity ($\beta = 1.60$), reusability ($\beta = 2.19$), transferability ($\beta = -2.05$), and ease of disassembly ($\beta = 2.58$).

Table 2 presents the results of the ordered probit regression model for how adequate Origami shelters are as a TEH solution postdisaster for Puerto Rico, with a pseudo-R^2 value of 0.3673. Several variables have p-values of less than or equal to 0.05, such as (1) lack of housing/shelter is a critical challenge; (2) lack of water and/or food is a critical challenge; (3) lack of electricity is a critical challenge; (4) health issues are a critical challenge; (5) mental health issues are a critical challenge; (6) delayed disaster recovery is a critical challenge; (7) having a shelter is a crucial need; (8) return to work and routine activities is a crucial need; (9) having water and food are crucial needs; (10) having electricity is a crucial need; (11) emotional recovery is a crucial need; (12) lightweight is a crucial feature for TEH; (13) deployable is crucial for TEH; (14) large production capacity is crucial for TEH; (15) reusability is crucial for TEH; (16) transferability is crucial for TEH; (17) material sustainability is crucial for TEH; and (18) easy disassembly is crucial for TEH. Therefore, it can be concluded that the data are statistically significant given that the hypothesis pertaining to the existence of the true relationship between the dependent variable, i.e., whether Origami shelters are an adequate solution for TEH postdisaster, and independent variables is correct.

In Table 2, μ_1, μ_2, μ_3, and μ_4 are the coefficients of the ordered probit model with the values of 3.91, 4.18, 5.88, and 6.55, respectively. These values are the threshold that reflects the predicted cumulative probabilities at covariate values of zero. Finally, based on the obtained results from the regression analysis, several variables will greatly contribute to the adequacy of Origami shelters as a solution for TEH postdisaster, including (1) critical challenges such as lack of housing/shelter ($\beta = -2.59$), lack of water and food ($\beta = -5.66$), lack of electricity ($\beta = 3.10$), health issues ($\beta = 1.79$); mental health issues ($\beta = -2.76$); and delayed disaster recovery ($\beta =$

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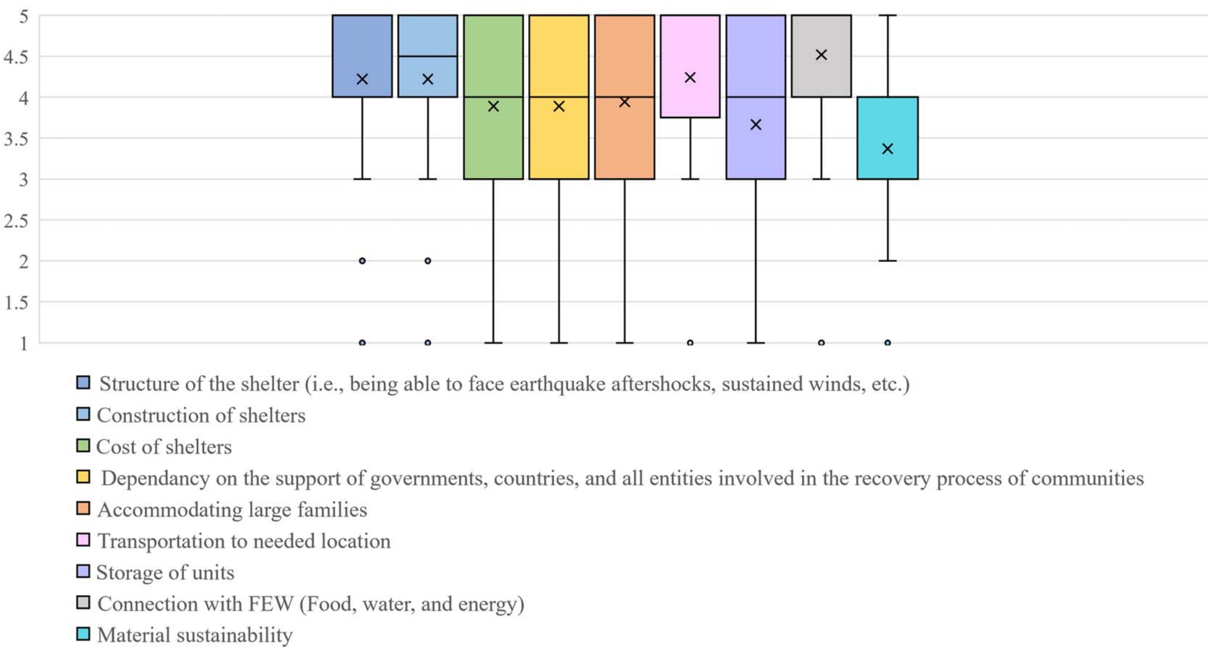

Fig. 8. Biggest challenges of the proposed solution in Puerto Rico.

−4.16); (2) crucial needs such as having a shelter postdisaster ($\beta = 4.58$), return to work and routine activities ($\beta = -2.52$), having water and food ($\beta = 11.20$), having electricity ($\beta = -3.69$), and emotional recovery ($\beta = 2.79$); and (3) crucial features required in a TEH, such as lightness ($\beta = 2.64$), deployable ($\beta = -5.15$), high production capacity ($\beta = 1.77$), reusability ($\beta = 3.09$), transferability ($\beta = 5.07$), material sustainability ($\beta = -2.37$), and ease of disassembly ($\beta = -2.43$).

Finally, this study aimed to identify additional challenges, vulnerabilities, and crucial needs that communities face postdisaster, as well as characteristics that experts considered crucial in temporary emergency shelters to be an optimal TEH solution postdisaster.

Table 1. Coefficients and P-values from ordered probit analysis for Peru

Variables	Coeff. (β)	Std. error	Z	P-value
Lack of housing/shelter is a critical challenge	−3.99	1.56	−2.56	0.011
Lack of water and/or food is a critical challenge	−3.72	0.72	−5.16	0.000
Lack of electricity is a critical challenge	−0.04	0.42	−0.10	0.918
Feeling unsafe is a critical challenge	1.93	0.50	3.86	0.000
Health issues are a critical challenge	−1.61	1.04	−1.55	0.121
Mental health issues is a critical challenge	0.71	0.48	1.49	0.136
Delayed disaster recovery is a critical challenge	1.24	0.56	2.22	0.027
Having a shelter is a crucial need	3.75	1.56	2.41	0.016
Return to work and routine activities is a crucial need	0.47	0.48	0.98	0.328
Having water and food is a crucial need	−0.19	0.89	−0.21	0.832
Having electricity is a crucial need	−0.84	0.48	−1.74	0.081
Emotional recovery is crucial need	0.53	0.56	0.95	0.341
Easy and quickly assembly is crucial for TEH	1.64	0.72	2.26	0.024
Lightweight is a crucial feature for TEH	−2.25	0.58	−3.85	0.000
Readily availability is crucial for TEH	2.67	0.77	3.46	0.001
Deployability is crucial for TEH	0.32	0.68	0.47	0.636
Easy storage of units is crucial for TEH	−3.24	0.77	−4.23	0.000
Large production capacity is crucial for TEH	1.60	0.55	2.92	0.003
Reusability is crucial for TEH	2.19	0.59	3.71	0.000
Recyclability is crucial for TEH	0.92	0.68	1.36	0.174
Transferability is crucial for TEH	−2.05	0.52	−3.92	0.000
Using sustainable material is crucial for TEH	0.76	0.53	1.45	0.147
Low environmental impact is crucial for TEH	0.78	0.71	1.09	0.274
Easy disassembly is crucial for TEH	2.58	0.61	4.25	0.000
μ_1	−1.35	0.61	—	—
μ_2	−0.77	0.81	—	—
μ_3	0.58	0.80	—	—
μ_4	2.41	0.85	—	—
Number of observations	—	—	—	65
Pseudo-R^2	—	—	—	0.4073

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Table 2. Coefficients and P-values from ordered probit analysis for Puerto Rico

Variables	Coeff. (β)	Std. error	Z	P-value
Lack of housing/shelter is a critical challenge	−2.59	0.95	−2.73	0.006
Lack of water and/or food is a critical challenge	−5.66	2.36	−2.40	0.017
Lack of electricity is a critical challenge	3.10	1.00	3.11	0.002
Feeling unsafe is a critical challenge	−0.44	0.97	−0.45	0.651
Health issues are a critical challenge	1.79	0.72	2.50	0.012
Mental health issues is a critical challenge	−2.76	0.96	−2.87	0.004
Delayed disaster recovery is a critical challenge	−4.16	1.75	−2.37	0.018
Having a shelter is a crucial need	4.58	2.21	2.07	0.038
Return to work and routine activities is a crucial need	−2.52	1.17	−2.15	0.031
Having water and food is a crucial need	11.20	3.59	3.12	0.002
Having electricity is a crucial need	−3.69	1.50	−2.47	0.014
Emotional recovery is crucial need	2.79	1.26	2.22	0.027
Easy and quickly assembly is crucial for TEH	3.35	1.81	1.85	0.064
Lightweight is a crucial feature for TEH	2.64	0.84	3.16	0.002
Readily availability is crucial for TEH	0.22	0.93	0.23	0.815
Deployability is crucial for TEH	−5.15	1.55	−3.32	0.001
Easy storage of units is crucial for TEH	0.58	0.81	0.72	0.472
Large production capacity is crucial for TEH	1.77	0.89	2.00	0.045
Reusability is crucial for TEH	3.09	1.13	2.74	0.006
Recyclability is crucial for TEH	0.58	0.84	0.69	0.491
Transferability is crucial for TEH	5.07	1.50	3.37	0.001
Using sustainable material is crucial for TEH	−2.37	1.15	−2.06	0.040
Low environmental impact is crucial for TEH	−2.61	1.34	−1.95	0.052
Easy disassembly is crucial for TEH	−2.43	0.79	−3.07	0.002
μ_1	3.91	2.99	—	—
μ_2	4.18	2.94	—	—
μ_3	5.88	2.87	—	—
μ_4	6.55	2.88	—	—
Number of observations	—	—	—	54
Pseudo-R^2	—	—	—	0.3673

Peruvian experts consider that (1) significant challenges and vulnerabilities encompass lack of communication, economic instability, transportation issues, lack of food, and employment loss; (2) crucial needs include communication, medical attention and healthcare, economic recovery, and safety; and (3) essential characteristics for TEH include durability, resilience, ability to withstand local conditions and natural disasters, easy transportation, easy assembly, and cost-effectiveness. These results are presented in Fig. 9. Puerto Rican experts consider that (1) significant challenges and vulnerabilities encompass lack of communication, transportation issues, and lack of support; (2) crucial needs include communication, sanitation, and gas; and (3) essential characteristics for TEH include cost-effectiveness, safe and resilient shelter, easy assembly, easy storage, and weather resistance.

Discussion

This research highlighted the critical importance of investigating TEH as a solution postdisaster solution, emphasizing the need for quick-assembly shelters to provide a safe living environment for victims while their homes are undergoing repairs or reconstruction (Félix et al. 2020; Soleimani and Matini 2022). To assess the feasibility of the proposed Origami temporary emergency shelter, this study conducted surveys among experts in the AEC field in both Peru and Puerto Rico. These regions were chosen as the focus of the study based on their frequent exposure to natural disasters and heightened vulnerability due to financial constraints, substantial poverty rates, and informal construction (Degg and Chester 2005; Glave et al. 2008; Goldwyn et al. 2022; Talbot et al. 2022).

The results of the study highlight several similarities in postdisaster recovery between Peru and Puerto Rico: (1) around 65% of Peruvian experts and 60% of Puerto Rican experts consider that disaster recovery takes more than 1 year; (2) 98.5% of Peruvian experts and 98.1% of Puerto Rican experts consider it critical to investigate TEH; and (3) 85% of Peruvian experts and 87% of Puerto Rican experts consider that TEH could potentially improve victim's health and well-being. Furthermore, around 48% of Peruvian experts and 52% of Puerto Rican experts consider Origami shelter an excellent solution, while less than 5% of Peruvian and less than 6% of Puerto Rican experts consider it slightly good or not good. These findings align with the literature, which emphasizes that (1) low-income communities, highly exposed and vulnerable to natural disasters, often receive delayed disaster recovery efforts, including the implementation of TEH and emergency relief, which can take several months, or even years (Huang et al. 2022; Rendon et al. 2021); and (2) housing is crucial for overall well-being (Barakat 2003; Costanza et al. 2007).

The results of the ordered probit regression analysis indicated several similarities between the challenges, crucial needs, and characteristics of TEH for both regions. The analysis shows that several variables are significantly related to the adequacy of the proposed Origami shelter for both regions, including lack of housing is a critical challenge, lack of water and/or food is a critical challenge, delayed disaster recovery is a critical challenge, having a shelter is a crucial need, lightweight is a crucial feature for TEH, large production capacity is crucial for TEH, reusability is crucial for TEH, transferability is crucial for TEH, and easy disassembly is crucial for TEH. Moreover, experts from both regions reported similar additional challenges, vulnerabilities, and crucial needs, along with comparable essential characteristics for the proposed Origami shelter to serve as an adequate solution for TEH postdisaster. They emphasized (1) lack of communication and transportation issues as significant challenges; (2) communication as a crucial need; and

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Fig. 9. (a) Challenges; (b) crucial needs; and (c) characteristics of TEH for Peru and Puerto Rico.

(3) resilience, cost-effectiveness, and easy assembly as crucial characteristics. Therefore, it can be inferred that the major challenges, vulnerabilities, and crucial needs do not differ significantly and are, in fact, very similar between Peru and Puerto Rico.

According to the literature, (1) the adequate function of communication and transportation systems is key for effective disaster management (Urlainis et al. 2022); (2) natural disasters gravely impact individuals, causing infrastructure and property damage, injuries, and a reduction in the availability of essential resources such as FEW (El-Anwar et al. 2009; Hendriks and Opdyke 2022; UNDRR CRED 2020); and (3) the provision of a quick-to-assemble, lightweight, resilient, affordable, and sustainable TEH solution is paramount to ensure all victims have shelter after a natural disaster (Beatini et al. 2023; Johnson 2007; Rahat et al. 2023; Rendon et al. 2021; Shahzad et al. 2022). That said, the feedback provided by Peruvian and Puerto Rican experts regarding the challenges, crucial needs, and critical TEH characteristics closely align with the literature.

Limitations and Future Work

This study acknowledges some limitations. The survey responses might be subjective to self-assessment and biases and sampling bias due to the purposive sampling process used. Another limitation of the study is that it has been conducted only in Peru and Puerto Rico, affecting its scalability. However, these two developing regions are frequently exposed to natural disasters and are highly vulnerable to them, given their limited financial resources, significant levels of poverty, prevalence of informal construction, and sociopolitical factors, therefore rendering and reflecting the sample to be representative of developing regions with high poverty rates. Future studies could focus on investigating the research in other regions to look at additional challenges, crucial needs, and characteristics needed for TEH postdisaster. This research proposed and evaluated Origami TEH as an efficient and suitable short-term solution for providing shelter to disaster victims, leveraging its ease of assembly and disassembly, lightweight design, deployability, reusability, and transferability. This evaluation serves as the initial step within a comprehensive research framework. Subsequent phases of the framework should focus on assessing the feasibility and performance of Origami TEH in vulnerable territories with poor infrastructure. These phases would involve an depth evaluation of: (1) feasibility by considering factors such as cost-effectiveness, construction speed, scalability, ease of deployment, and the technological aspect; (2) performance in vulnerable territories with poor infrastructure, assessing structural resilience, adaptability to challenging environments, suitability for TEH, and resilience to natural disasters.; and (3) strategies to mitigate challenges associated with Origami TEH. Future studies could validate the proposed solution through case studies in diverse regions exposed to various natural disasters. The data collected from these studies would offer valuable insights for further evaluation and improvement of Origami TEH.

Conclusions

Having a home is a basic human need and is essential for the well-being of individuals, families, and communities. A temporary home allows victims to temporarily recover from disasters and potentially improve their health and well-being, as reflected by this study's results. More than 60% of Peruvian and Puerto Rican experts believe that disaster recovery can exceed 1 year, which supports the fact that disaster recovery after a major natural disaster can take an extended period of time. Furthermore, the recorded data emphasize the importance of investigating TEH as a post-disaster solution and highlight that the proposed Origami shelter is a very good and effective TEH solution for the housing crisis that arises and/or is further exacerbated postdisaster.

The results of this research reflect the challenges and vulnerabilities that low-income communities face postdisaster and the most important characteristics the proposed Origami shelter should have to be an optimal TEH solution postdisaster. The ordered probit regression analysis results indicate that certain variables contribute significantly for Origami shelter to be an adequate solution for TEH postdisaster for both Peru and Puerto Rico, including (1) lack of housing/shelter is a critical challenge; (2) having a shelter is a crucial need; (3) lightweight is a crucial feature for TEH; (4) large production capacity is crucial for TEH; (5) reusability is crucial for TEH; (6) transferability is crucial for TEH; and (7) easy disassembly is crucial for TEH. The proposed Origami solution fulfills all the aforementioned characteristics, thus making it an excellent and effective postdisaster TEH solution. The proposed Origami

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shelters, made of white polypropylene, an economic material, are fully recyclable and have a 20-year lifetime, ensuring durability and allowing for reusability and transferability. Furthermore, they can be folded, enabling easy and cost-reduced transportation, highlighting the economic feasibility of this solution. The findings of this study benefit both communities and their stakeholders by providing an innovative TEH solution, which offers an equitable, sustainable, affordable, and practical solution that can be effortlessly assembled in a couple of minutes. Consequently, the Origami TEH ensures swift and cost-effective shelter for all victims post-disaster, enabling them to reside safely and resume normal activities while their homes undergo repairs or reconstruction.

Data Availability Statement

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

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References

Araya, F., K. M. Faust, and J. A. Kaminsky. 2019. "Public perceptions from hosting communities: The impact of displaced persons on critical infrastructure." *Sustainable Cities Soc.* 48: 101508. https://doi.org/10.1016/j.scs.2019.101508.

Arslan, H., and N. Cosgun. 2008. "Reuse and recycle potentials of the temporary houses after occupancy: Example of Duzce, Turkey." *Build. Environ.* 43 (5): 702–709. https://doi.org/10.1016/j.buildenv.2007.01.051.

Atmaca, N. 2017. "Life-cycle assessment of post-disaster temporary housing." *Build. Res. Inf.* 45 (5): 524–538. https://doi.org/10.1080/09613218.2015.1127116.

Bannova, O., and M. Nystrom. 2015. "Architectural engineering approach to developing a matrix for planning in extreme environments." In *Earth and Space 2014*, 673–681. Reston, VA: ASCE.

Barakat, S. 2003. *Housing reconstruction after conflict and disaster*. London: Overseas Development Institute.

Beatini, V., H. Rajanayagam, and K. Poologanathan. 2023. "Structural and spatial minimal requirement efficacy of emergency shelters for different emergencies." *Buildings* 13 (1): 32. https://doi.org/10.3390/buildings13010032.

Brown, N. 2018. "Special Report: In Puerto Rico, a housing crisis U.S. storm aid won't solve." *Reuters*. Accessed October 1, 2023. https://www.reuters.com/article/us-usa-puertorico-housing-specialreport-idUSKBN1FQ211.

Burck, L., M. Kong, and P. Januário. 2015. "Paper architecture inspired in origami and emergency temporary architecture." In *Proc., 3rd Annual Int. Conf. on Architecture and Civil Engineering (ACE 2015)*. Singapore: Global Science and Technology Forum (GSTF).

Calle Müller, C., P. B. Santaniello, I. Zisis, A. Elawady, and M. Elzomor. 2023. "Towards developing a modernized wind engineering curricula." In *Proc., 2023 ASEE Annual Conf. & Exposition*. New York: American Society for Engineering Education (ASEE).

Chau, C. K., T. M. Leung, and W. Y. Ng. 2015. "A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings." *Appl. Energy* 143 (C): 395–413. https://doi.org/10.1016/j.apenergy.2015.01.023.

Costanza, R., et al. 2007. "Quality of life: An approach integrating opportunities, human needs, and subjective well-being." *Ecol. Econ.* 61 (2–3): 267–276. https://doi.org/10.1016/j.ecolecon.2006.02.023.

Criswell, M. E., and J. S. Carlson. 2004. "Concepts for the design and construction of a modular inflatable habitat." In *Proc., Engineering, Construction, and Operations in Challenging Environments: Earth and Space 2004*, 9–16, Reston, VA: ASCE.

Degg, M. R., and D. K. Chester. 2005. "Seismic and volcanic hazards in Peru: Changing attitudes to disaster mitigation." *Geogr. J.* 171 (2): 125–145. https://doi.org/10.1111/j.1475-4959.2005.00155.x.

Del Grosso, A. E., and P. Basso. 2010. "Adaptive building skin structures." *Smart Mater. Struct.* 19 (12): 124011. https://doi.org/10.1088/0964-1726/19/12/124011.

Dhakal, S., L. Zhang, A. M. Asce, and P. D. Candidate. 2022. "Integrating social equity and vulnerability with infrastructure resilience assessment." In *Proc., Construction Research Congress 2022*, edited by F. Jazizadeh, T. Shealy, and M. J. Garvin. Reston, VA: ASCE.

Domingos, L., and V. Rato. 2019. "Multi-criteria material selection for buildings in challenging environments." *IOP Conf. Ser. Earth. Environ. Sci.* 297(1): 012038. https://doi.org/10.1088/1755-1315/297/1/012038.

Dudte, L. H., E. Vouga, T. Tachi, and L. Mahadevan. 2016. "Programming curvature using origami tessellations." *Nat. Mater.* 15 (5): 583–588. https://doi.org/10.1038/nmat4540.

El-Anwar, O., K. El-Rayes, and A. Elnashai. 2009. "Optimizing large-scale temporary housing arrangements after natural disasters." *J. Comput. Civ. Eng.* 23 (2): 110–118. https://doi.org/10.1061/ASCE0887-3801200923:2110.

Félix, D., J. M. Branco, and A. Feio. 2013. "Temporary housing after disasters: A state of the art survey." *Habitat Int.* 40: 136–141. https://doi.org/10.1016/j.habitatint.2013.03.006.

Félix, D., D. Monteiro, and A. Feio. 2020. "Estimating the needs for temporary accommodation units to improve pre-disaster urban planning in seismic risk cities." *Sustainable Cities Soc.* 61: 102276. https://doi.org/10.1016/j.scs.2020.102276.

Filipov, E. T., T. Tachi, and G. H. Paulino. 2015. "Origami tubes assembled into stiff, yet reconfigurable structures and metamaterials." *Proc. Natl Acad. Sci. U. S. A.* 112 (40): 12321–12326. https://doi.org/10.1073/pnas.1509465112.

Geological Survey (US), Bush, D. M., B. R. Richmond, and W. J. Neal. 1996. *Coastal zone hazards maps of Puerto Rico: Hurricane hugo impacted portion of the shoreline, Cibuco (Punta Garaza) to Punta Viento by open-file report 96-506*. Reston, VA: U.S. Geological Survey.

Glave, M., R. Fort, and C. Rosemberg. 2008. *United nations development programme regional bureau for Latin America and the Caribbean disaster risk and poverty in Latin America: The Peruvian case study*. New York: RBLAC-UNDP.

Goldwyn, B., A. Javernick-Will, and A. B. Liel. 2022. "Multi-hazard housing safety perceptions of those involved with housing construction in Puerto Rico." *Sustainability* 14 (7): 3802. https://doi.org/10.3390/su14073802.

Hartl, D., K. Lane, and R. Malak. 2012. "Computational design of a reconfigurable origami space structure incorporating shape memory alloy thin films." In: Vol. 2 of *ASME 2012 Conf. on Smart Materials, Adaptive Structures and Intelligent Systems, SMASIS 2012*, 277–285. New York: ASME.

Hausler, E. 2010. "Building earthquake-resistant houses in Haiti: The homeowner-driven model." *Innovations* 5 (4): 91–115. https://doi.org/10.1162/INOV_A_00047.

He, Y., B. Wu, P. He, W. Gu, and B. Liu. 2021. "Wind disasters adaptation in cities in a changing climate: A systematic review." *PLoS One* 16 (3): e0248503. https://doi.org/10.1371/journal.pone.0248503.

Hendriks, E., and A. Opdyke. 2022. "The influence of technical assistance and funding on perceptions of post-disaster housing safety after the 2015 Gorkha earthquakes in Nepal." *Int. J. Disaster Risk Reduct.* 73: 102906. https://doi.org/10.1016/j.ijdrr.2022.102906.

Home Harmonizing. n.d. "The flat-packed 'Compact Shelter' by Alastair Pryor." Accessed April 27, 2023. https://homeharmonizing.com/flat-packed-compact-shelter-pops-up-to-morph-into-an-emergency-habitable-unit/.

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Hong Park, J. 2021. "Tensegami: Design principle of combining tensegrity and origami to make geodesic dome structure for Martian agriculture." In *Earth and Space 2021*, edited by P. J. van Susante, and A. D. Roberts, 978–984, Reston, VA: ASCE.

Hosseini, S. M. A., R. Yazdani, and A. de la Fuente. 2020. "Multi-objective interior design optimization method based on sustainability concepts for post-disaster temporary housing units." *Build. Environ.* 173: 106742. https://doi.org/10.1016/j.buildenv.2020.106742.

Huang, L., P. Shi, and H. Zhu. 2022. "An integrated urgency evaluation approach of relief demands for disasters based on social media data." *Int. J. Disaster Risk Reduct.* 80: 103208. https://doi.org/10.1016/j.ijdrr.2022.103208.

IFRC (International Federation of Red Cross and Red Crescent Societies). 2020. *World disasters report 2020: Come heat or high water*. Geneva: IFRC.

Ihuah, P. W., I. I. Kakulu, and D. Eaton. 2014. "A review of Critical Project Management Success Factors (CPMSF) for sustainable social housing in Nigeria." *Int. J. Sustainable Built Environ.* 3 (1): 62–71. https://doi.org/10.1016/j.ijsbe.2014.08.001.

INDECI. 2007. *Movimiento Sísmico afecta severamente Departamentos de Ica y Sur de Lima: Informe de emergencia N°322, 16/09/2007*. Lima: INDECI.

Johnson, C. 2007. "Impacts of prefabricated temporary housing after disasters: 1999 earthquakes in Turkey." *Habitat Int.* 31 (1): 36–52. https://doi.org/10.1016/j.habitatint.2006.03.002.

Kenny, C. 2009. "Why do people die in earthquakes? The costs, benefits and institutions of disaster risk reduction in developing countries." In *The Costs, Benefits and Institutions of Disaster Risk Reduction in Developing Countries (January 1, 2009). World Bank Policy Research Working Paper*. (4823), 1–42. Washington, DC: The World Bank.

Kishore, N., et al. 2018. "Mortality in Puerto Rico after hurricane Maria." *N. Engl. J. Med.* 379 (2): 162–170. https://doi.org/10.1056/nejmsa1803972.

Li, S., H. Fang, S. Sadeghi, P. Bhovad, and K.-W. Wang. 2019. "Architected origami materials: How folding creates sophisticated mechanical properties." *Adv. Mater.* 31 (5): e1805282. https://doi.org/10.1002/adma.201805282.

Lindell, M. K., and C. S. Prater. 2003. "Assessing community impacts of natural disasters." *Nat. Hazards Rev.* 4 (4): 176–185. https://doi.org/10.1061/ASCE1527-698820034:4176.

Llorente-Marrón, M., M. Díaz-Fernández, P. Méndez-Rodríguez, and R. G. Arias. 2020. "Social vulnerability, gender and disasters. The case of Haiti in 2010." *Sustainability* 12 (9): 3574. https://doi.org/10.3390/SU12093574.

Lu, W., V. W. Y. Tam, H. Chen, and L. Du. 2020. "A holistic review of research on carbon emissions of green building construction industry." *Eng. Constr. Archit. Manage.* 27 (5): 1065–1092. https://doi.org/10.1108/ECAM-06-2019-0283.

Maciejewska, A., Ł Kuzak, M. Ulanicka-Raczyńska, and K. Moreau. 2022. "Land management using land reserves to alleviate emergencies on the example of Warsaw." *Sustainability* 14 (18): 11625. https://doi.org/10.3390/su141811625.

Mannheim, V., and Z. Simenfalvi. 2020. "Total life cycle of polypropylene products: Reducing environmental impacts in the manufacturing phase." *Polymers* 12 (9): 1901. https://doi.org/10.3390/POLYM12091901.

Marchigiani, R., et al. 2013. "Wind disasters: A comprehensive review of current management strategies." *Int. J. Crit. Illn. Inj. Sci.* 3 (2): 130. https://doi.org/10.4103/2229-5151.114273.

Maskrey, A. 1989. *Disaster mitigation: A community based approach*. Nairobi, Kenya: Oxfam International.

Masozera, M., M. Bailey, and C. Kerchner. 2007. "Distribution of impacts of natural disasters across income groups: A case study of New Orleans." *Ecol. Econ.* 63 (2–3): 299–306. https://doi.org/10.1016/j.ecolecon.2006.06.013.

Mastroianni, E., J. Lancaster, B. Korkmann, A. Opdyke, and W. Beitelmal. 2021. "Mitigating infrastructure disaster losses through asset management practices in the Middle East and North Africa region." *Int. J. Disaster Risk Reduct.* 53: 102011. https://doi.org/10.1016/j.ijdrr.2020.102011.

Meloni, M., J. Cai, Q. Zhang, D. Sang-Hoon Lee, M. Li, R. Ma, T. E. Parashkevov, and J. Feng. 2021. "Engineering origami: A comprehensive review of recent applications, design methods, and tools." *Adv. Sci.* 8 (13): 2000636. https://doi.org/10.1002/advs.202000636.

Miller, S. J., and M. A. Vela. 2014. *Is disaster risk reduction spending driven by the occurrence of natural disasters?* Evidence from Peru, Washington, DC: Inter-American Development Bank.

Pradhananga, P., C. Calle Müller, R. Rahat, and M. Elzomor. 2023. "Investigating the need for forensic engineering graduate program to meet the growing workforce demand." In *Proc., 2023 ASEE Annual Conf. & Exposition*. New York: American Society for Engineering Education (ASEE).

Pradhananga, P., A. Elawady, and M. ElZomor. 2022. "Leveraging informal learning pedagogies to empower coastal communities for disaster preparedness." *Front. Built Environ.* 8: 883198. https://doi.org/10.3389/fbuil.2022.883198.

Rahat, R., P. Pradhananga, C. Calle Muller, and M. ElZomor. 2023. "Multi-criteria evaluation of Safe-to-Fail flood solution alternatives for developing resilient coastal cities." *Sustainable Resilient Infrastruct.* 8 (6): 610–625. https://doi.org/10.1080/23789689.2023.2257503.

Rendon, C., K. K. Osman, and K. M. Faust. 2021. "Path towards community resilience: Examining stakeholders' coordination at the intersection of the built, natural, and social systems." *Sustainable Cities Soc.* 68: 102774. https://doi.org/10.1016/j.scs.2021.102774.

Rosemberg, C., R. Fort, and M. Glave. 2010. "Effect of natural disasters on poverty transitions and consumption growth. Evidence from rural Peru." *Well-being Soc. Policy* 6 (1): 55–94.

San Bartolomé, A., D. Quiun, and L. Zegarra. 2008. "Performance of reinforced adobe houses in Pisco, Peru earthquake." In *Proc., 14th World Conf. on Earthquake Engineering*. Beijing: World Conference on Earthquake Engineering (WCEE).

Shahzad, W. M., G. Rajakannu, and N. Kordestani Ghalenoei. 2022. "Potential of modular offsite construction for emergency situations: A New Zealand study." *Buildings* 12 (11): 1970. https://doi.org/10.3390/buildings12111970.

Shapira, S., L. Aharonson-Daniel, I. M. Shohet, C. Peek-Asa, and Y. Bar-Dayan. 2015. "Integrating epidemiological and engineering approaches in the assessment of human casualties in earthquakes." *Nat. Hazards* 78, 1447–1462 https://doi.org/10.1007/s11069-015-1780-0.

Soleimani, K., and M. R. Matini. 2022. "Reusing earthquake rubble in a temporary housing structure for hot arid climates." *J. Archit. Eng.* 28 (2): 04022015. https://doi.org/10.1061/(ASCE)AE.1943-5568.00005.

Talbot, J., C. Poleacovschi, and S. Hamideh. 2022. "Socioeconomic vulnerabilities and housing reconstruction in Puerto Rico after hurricanes Irma and Maria." *Nat. Hazards* 110 (3): 2113–2140. https://doi.org/10.1007/s11069-021-05027-7.

Tinman, M., D. Quiun, A. Muñoz, and L. Speicher. 2017. "Seismic protection of buildings in Peru using energy dissipation and base isolation." In *Proc., 16th World Conf. on Earthquake Engineering*. Santiago, Chile: World Conference on Earthquake Engineering (WCEE).

UNDRR CRED. 2020. *Human cost of disasters: An overview of the last 20 years 2000–2019*. Brussels, Belgium: CRED, UNDRR.

United Nations Environment Programme. 2009. *Common carbon metric for measuring energy use and reporting greenhouse gas emissions from building operations*. New York: United Nations Environment Programme (UNEP).

Urlainis, A., D. Ornai, R. Levy, O. Vilnay, and I. M. Shohet. 2022. "Loss and damage assessment in critical infrastructures due to extreme events." *Saf. Sci.* 147: 105587. https://doi.org/10.1016/j.ssci.2021.105587.

Wei, H.-H., M. J. Skibniewski, I. M. Shohet, and X. Yao. 2016. "Lifecycle environmental performance of natural-hazard mitigation for buildings." *J. Perform. Constr. Facil.* 30 (3): 04015042. https://doi.org/10.1061/(asce)cf.1943-5509.0000803.

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