Integrating Stakeholder Value Dynamics with Resilience Evaluation for Housing

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ABSTRACT

Enhancing housing resilience requires us to choose a path that can systematically assess the value of resilience to the housing stakeholders. However, there is a lack of methods that assess housing resilience value by considering stakeholders' perspectives. To address this gap, this paper proposes a human-centered resilience evaluation framework that integrates stakeholder value systems and dynamics with resilience evaluation. The model mathematically incorporates (1) the degree that a resilience asset fulfills stakeholder values (i.e., resilience fulfillment degree), (2) stakeholder value systems and dynamics in a disaster, and (3) the integration and alignment between resilience fulfillment degree and stakeholder value systems. The use of the model was illustrated through an experimental case study that assesses the resilience value of two alternative housing projects in the context of a hurricane disaster. This framework offers a unique approach that integrates human perspectives with resilience assessment and facilitates human-centered resilience designs or strategies.

INTRODUCTION

Urbanization has led to increased exposure to different hazards due to inadequate housing planning, poorly regulated building codes, and a lack of proactive adaptation to climate change (Bosher 2014). The importance of disaster resilience in housing planning and design has been recognized by housing stakeholders (Ahmed et al. 2018). According to the National Academy of Sciences, the path to enhance disaster resilience should acknowledge and reward its value to individuals, households, communities, and nations (NAS 2012). However, there is little guidance for communities to evaluate their assets' resilience value in disaster situations while considering stakeholders' perspectives. The lack of an effective value measurement method has resulted in debates over the costs and effectiveness of disaster resilience strategies. Therefore, it is essential to understand stakeholder value systems and their priorities in the context of disaster resilience to facilitate the measurement of resilience value.

Stakeholder value systems refer to ranked systems of things that are important to stakeholders (Zhang and El-Gohary 2016). These systems are dynamic, time-sensitive, and could be influenced by significant life events such as wars, migration, and disasters (Tormos et al. 2017; Bardi et al. 2014). During a disaster event, stakeholders often experience a significant shift in their value priorities compared to their priorities during non-disaster times. To better measure the value of resilience, it is crucial that we identify stakeholder value systems and their dynamics in a disaster and integrate stakeholder value dynamics with resilience evaluation.

While extensive studies (e.g., Cimellaro et al. 2016; Kammouh et al. 2018; Chang et al. 2014; Cimellaro et al. 2014; Liu et al. 2017; Ouyang et al. 2012) have been conducted on analyzing or evaluating the resilience of built environments, there is limited research that considers stakeholder perspectives or values in resilience evaluation. Some recent studies have accounted for stakeholder perspectives in developing resilience metrics or measurements. For instance, Morelli et al. (2021) developed a metric-based resilience index that incorporates multilevel stakeholders' views in assessing the resilience of communities in coastal areas. Tokazhanov et al. (2021) collected and analyzed stakeholder opinions on the importance of resilience indicators and used them as weights to measure the resilience of residential buildings. However, in these studies, stakeholder views or opinions were assumed as constant constructs that did not change over time. In other words, these studies didn't account for the dynamics of stakeholder value systems on resilience, especially in a disaster context. As such, traditional resilience evaluation models may not fully capture the complexity of stakeholder values and their impacts on resilience in a disaster context.

To address such a gap, this paper proposes a human-centered resilience evaluation model that integrates stakeholder value dynamics with resilience evaluation (SVD-RE) to quantify resilience value to stakeholders in a disaster context. The model builds on the Build-Infra-Axio developed by Zhang and El-Gohary (2021) and the resilience triangle framework by Bruneau et al. (2003). The remainder of the paper focuses on presenting the model and a case study that demonstrates the use of the model in evaluating the resilience of alternative housing projects in a hurricane context.

STAKEHOLDER-VALUE-DYNAMIC-DRIVEN RESILIENCE EVALUATION(SVD-RE) MODEL FOR HOUSING

The SVD-RE model proposed in this study seeks to assess the value of alternative resilient housing projects to stakeholders based on their value dynamics. To formally represent and define the conceptual notions and relationships in the evaluation process, a high-level conceptual model (Figure 1) was developed.

According to the conceptual model, the SVD-RE has several key components, including stakeholder, resilience asset, stakeholder value, resilience fulfillment degree (RFD), stakeholder value priority (SVP), value of resilience (VR), stakeholder value dynamics (SVD), and loss of value of resilience (LVR). The explanation of each concept is presented below:

- A stakeholder is defined as an individual or an organization that is responsible for, impacted by, or interested in the development or management of a housing project (Zhang and El-Gohary 2021). Stakeholders may include homeowners, designers, contractors, facility managers, building end-users, local communities, media representatives, environmentalists, or interest group representatives.
- A resilience asset is an asset that can be evaluated through the SVD-RE, such as a housing design alternative, a housing design strategy, or a component of a house (e.g., windows, doors, roofs).
- A stakeholder value refers to a thing that is valued by a stakeholder (Zhang and El-Gohary 2021, Gosain et al. 2022). In this study, we focus on stakeholder values that are related to housing resilience. A list of stakeholder values on housing resilience was published in Gosain et al. (2022).
- The resilience fulfillment degree (RFD) is a numerical measure representing the degree to which a resilience asset fulfills resilience-related stakeholder values. RFD is heavily influenced by the characteristics of the resilience asset, such as the choice of building

materials. For example, a housing design that uses concrete blocks may better fulfill the stakeholder value of structural robustness compared to a design that uses wood materials. In this study, we adapted multiple research methods in measuring the degrees that a resilience asset fulfills various stakeholder values. Some examples of methods are presented in Table 2.

- The stakeholder value priority (SVP) is a quantitative measure of the importance or significance of a particular value to a stakeholder in fulfilling housing resilience. Different stakeholders may prioritize different values, and these priorities may change over time, particularly in the context of a disaster. To account for this change, the stakeholder value dynamics (SVD) is introduced in the model, representing the change of stakeholder value priorities at different phases of a disaster, such as disaster mitigation, preparedness, response, and recovery.
- The value of resilience (VR) is a quantifiable amount of the value of the resilience asset based on RFDs, SVPs, and SVDs. It builds on Zhang and El-Gohary (2021)'s Build-Infra-Axio. Different from Build-Infra-Axio, in our study, VR is dynamic and depends on the changes in stakeholder value priorities throughout different phases of a disaster. For instance, a house with expensive impact-resistant windows may not offer high VR to a home buyer who prioritizes affordability before a disaster but offers high VR after a disaster when the buyer prioritizes safety and robustness. The VR function has two subfunctions: (1) a Simple Additive Weighting (SAW) subfunction (Afshari et al. 2010) that aggregates the RFDs and SVPs of each stakeholder value, and (2) a Value Alignment Degree (VAD) subfunction that measures the alignment between SVPs and RFDs using Kendall's tau-b correlation coefficient, which ranges from -1 (perfectly negative alignment) to 1 (perfectly positive alignment). The VR function is represented through Eq. (1).

$$VR_{ht} = (\sum_{1}^{n} RFD_{ht} * SVP_{vt}) * (1 + \tau\mathrm{b})^{\alpha} \quad (1)$$

where VR_{ht} is the VR of housing h at time point t of a disaster; n is the total number of stakeholder values; RFD_{ht} is the resilience fulfillment degree of housing h at time point t of a disaster; SVP_{vt} is the priority of stakeholder value v at time point t of a disaster; τb is the alignment value that ranges from -1 to 1; and α is a coefficient that controls the degree of accounting for value alignment or misalignment.

- Loss of value of resilience (LVR) is the change of the VR due to a disruptive event such as a hurricane. LVR is determined by measuring the area of a resilience triangle by adapting the work of Bruneau et al. (2003) and Hossain et al. (2021) (Figure 2), which quantitatively measures the resilience of communities. LVR is expressed mathematically in Eq. (2):

$$LVR_h = \int_{t_0}^{t_2} [VR_{h0} - VR_{hd}(t)] dt \quad (2)$$

where LVR_h represents the change in resilience value of housing h over the time period from t_0 to t_2; t_0 is the point of time when the disaster occurs; t_2 is the point of time when the recovery is completed; VR_{h0} is the VR of housing h before a disaster; and $VR_{hd}(t)$ is the VR of housing h after a disaster occurs.

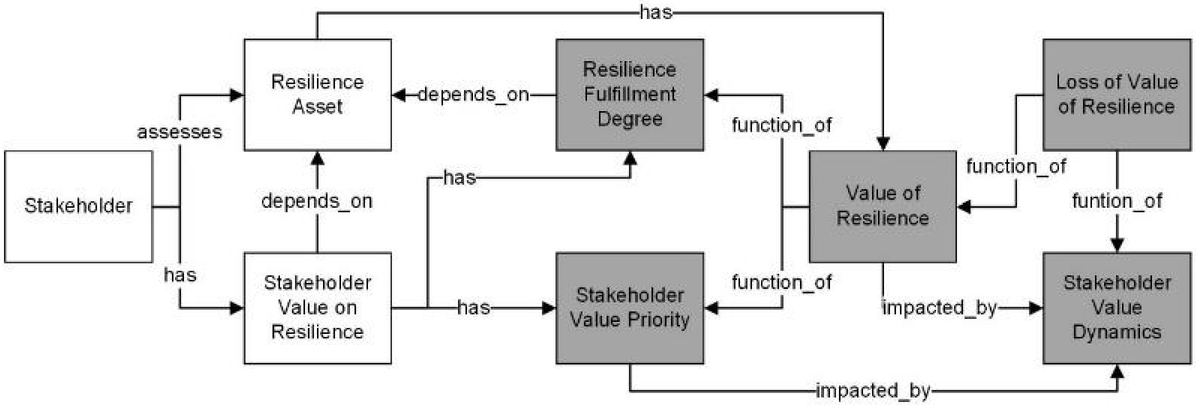

Figure 1. SVD-RE model.

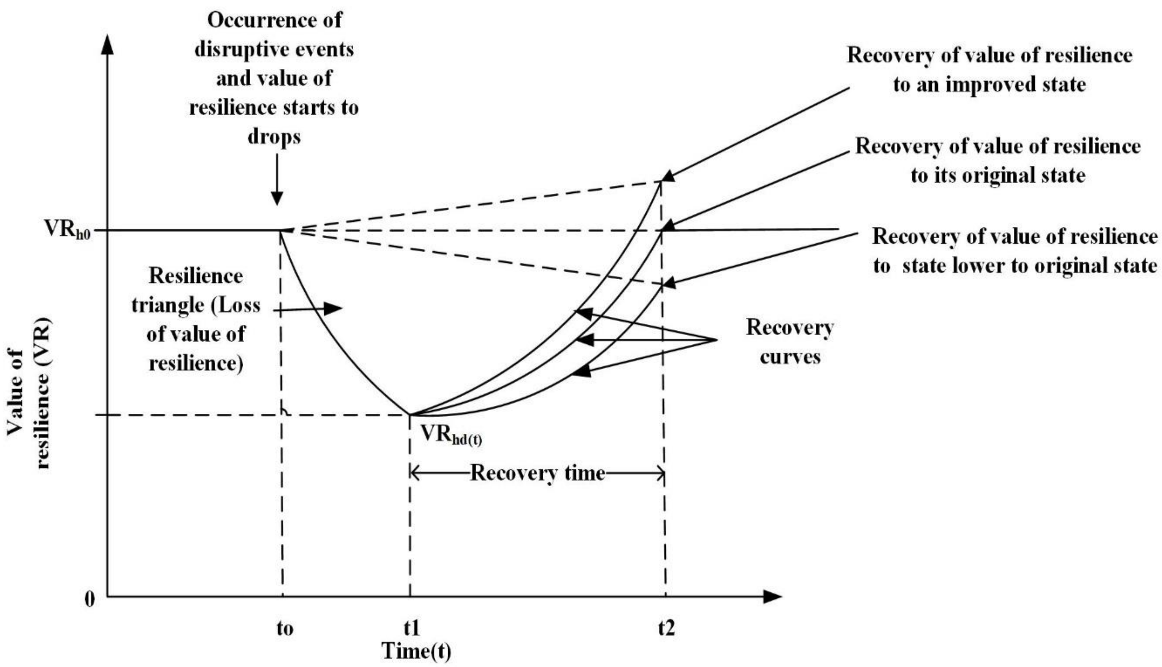

Figure 2. Measure of loss of value of resilience (adapted from Bruneau et al. 2003 and Hossain et al. 2021).

In summary, the SVD-RE model provides a framework for evaluating the value of resilient housing projects to the stakeholders. This framework accounts for the dynamic nature of stakeholder value priorities at different phases of a disaster, allowing for more human-centered assessments of the value of resilience assets.

CASE STUDY

To demonstrate the use of the model, we conducted an experimental case study that focuses on evaluating the LVRs of two housing projects in a hypothetical Category 5 hurricane. The design information of the two alternative housing projects is briefly summarized in Table 1.

Table 1. Design information of two alternative housing projects (HP).

System	Component	HP 1	HP 2
Exterior Wall	Name	Concrete block masonry wall	Wood wall
	Structure/framing	Concrete block (8” ×8” ×16”)	Wall framing with 2” × 6” lumber
	Interior sheathing	5/8” Type X gypsum board	5/8” Type X gypsum board
	Insulation	3” Fiberglass board rigid insulation	7-3/8” Expanded Polystyrene (EPS) foam
	Exterior finish	Wood lap siding	Stone veneer
Roof	Name	Gable roof (9:12 slope)	Flat roof
	Exterior finish	Clay tiles (19” ×11”)	Asphalt shingles (12” × 36”)
	Interior sheathing	1’-4” thick gypsum wallboard ASTM standard C1396, C36	1’-4” thick gypsum wallboard ASTM standard C1396, C36
	Insulation	2 layers of 3” Fiberglass board rigid insulation	9-3/8” EPS foam
Windows	Name	Sliding window	Single hung window
	Frame	Aluminum frame	Wooden frame
	Glass	1/8” double pane glass	3/16” single glass
	Shutter	Roller shutter	Board and Batten shutter
Door	Name	Wooden door	Hollow steel flush door
	Door panel	Wood	Steel

In the hypothetical hurricane, we assumed that the VR would decline to its lowest point within a week of the hurricane’s onset and that the recovery process would take roughly eight weeks, which was estimated based on Zorn and Shamseldin (2015). We engaged a diverse group of stakeholders, including homeowners, designers, contractors, and facility managers. Based on the SVD-RE model, the case study includes five primary steps: (1) defining housing designs, (2) selecting stakeholder values, (3) assessing RFDs, (4) determining SVPs, and (5) quantifying VRs and LVRs.

We first planned and designed two alternative housing projects located in different neighborhoods of Miami. Each housing project features different housing designs, with input from two architects to ensure compliance with the Florida building code. Both projects have a single-family home with the same layout, but with different structures and/or materials for building elements such as walls, roofs, doors, and windows.

We selected six stakeholder values for analysis in this case study. The six stakeholder values are affordability (V1), structural robustness and integrity (V2), energy efficiency (V3), connectivity (V4), safety and security (V5), and comfort and health (V6) (Figure 3). These values cover the dimensions of environmental, social, economic, and physical built environment resilience in the stakeholder value framework described in Gosain et al. (2022) and were generally highly prioritized based on multisector stakeholder perspectives (Gosain et al. 2022).

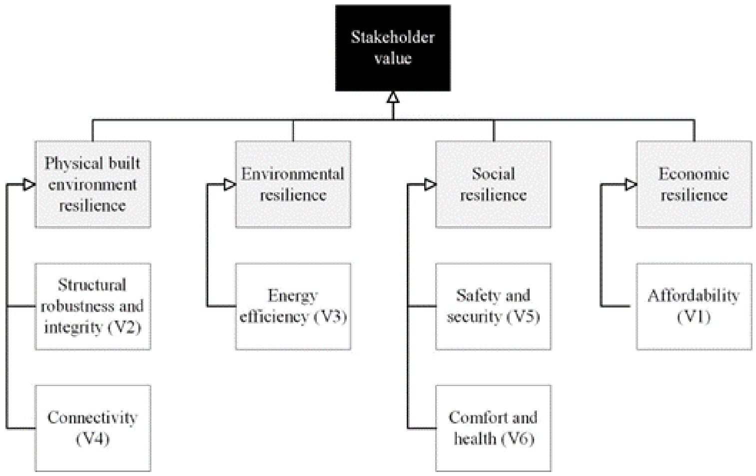

Figure 3. Stakeholder values selected for analysis.

We measured the RFDs of the housing projects in fulfilling each selected stakeholder value. The methods for RFD measurement are briefly summarized in Table 2. The RFDs of the housing projects in fulfilling the six stakeholder values during three phases of disaster are shown in Table 3.

Table 2. Methods of RFD measurement.

Stakeholder value	Method	Source
Affordability	Used a housing affordability index that measures the ability to purchase a home based on income	(Bekker et al. 2020)
Structural robustness and integrity	Used a robustness index that measures load carrying capacity of a building	(Adam et al. 2018)
Energy efficiency	Simulated and estimated the amount of energy consumption through eQUEST	(Ke et al. 2013)
Comfort and health	Used the Combined Comfort Index that integrates the measurements of thermal, acoustic, and lighting comforts	(Buratii et al. 2018)
Connectivity	Used the Connectivity Index that measures distances between the house and the closest facilities of interest.	(Carl et al. 2011)
Safety and security	Used the Security Index based on crime rate data	(Neighborhood Scout 2022)

We then utilized the Analytic Hierarchy Process (AHP) survey (Saaty 1987) to determine the SVPs and SVDs in the context of a Category 5 hurricane. The target respondents were stakeholders in the Miami region with experiences or knowledge of hurricane disasters, including those that were responsible for, impacted by, or interested in housing projects, such as a home developer, a contractor representative, an architect, or a resident. The survey focuses on soliciting stakeholders' opinions on the importance of the six selected values at three disaster phases: (1) before a disaster (mitigation), (2) during a disaster (preparedness and response), and (3) after a disaster (recovery). The survey is structured following the AHP method, and it organizes the six stakeholder values in pairs for comparison. It asks the respondents to compare the importance of each pair of values using a scale of 1 to 9, with 9 as "Absolutely More Important" and 1 as "Equally Important". For the experimental study, a total of 20 responses were collected.

Table 3. RFDs of five housing projects.

Stakeholder value	RFDs					
	Before the disaster		During the disaster		After the disaster	
	HP 1	HP 2	HP 1	HP 2	HP 1	HP 2
V1	0.723	0.740	0.578	0.592	0.723	0.740
V2	0.933	0.905	0.467	0.452	0.933	0.905
V3	0.480	0.460	0.192	0.184	0.480	0.460
V4	0.451	0.360	0.315	0.252	0.451	0.360
V5	0.777	0.199	0.505	0.129	0.777	0.199
V6	0.343	0.398	0.206	0.239	0.343	0.398

RESULTS

By using Eq. (1), the VR of each housing project was assessed for every respondent before, during, and after a disaster. The α coefficient was set to 0.5, which represents a medium extent of rewarding/penalizing alignment/misalignment between RFDs and SVPs. To determine the LVR of each housing project and stakeholder, we calculated the area of the triangle formed by three coordinate points that reflect the VR values at the three stages of the disaster. Figure 4 illustrates an example of a resilience triangle based on the VRs of HP 1 to Respondent 1 (R1).

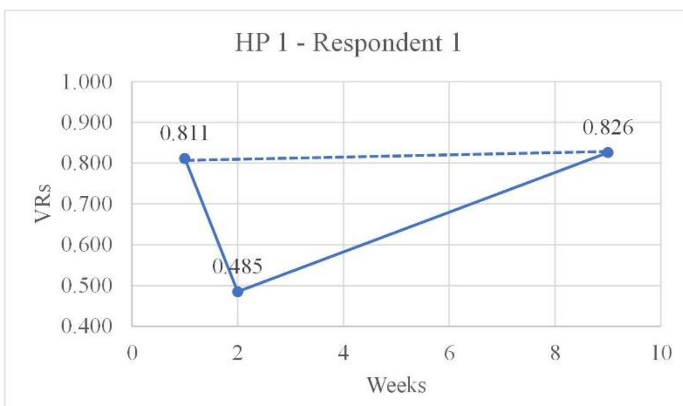

Figure 4. A resilience triangle of HP 1 based on the SVPs and SVD of stakeholder 1.

The LVRs of the two housing projects to different respondents are presented in Table 4. A lower LVR indicates that, based on the respondent's value dynamics, the project lost less value in the hurricane, and is favored by that respondent. As per Table 4, the two housing projects have different LVRs to different respondents even though they are exposed in the same disaster. Moreover, the same housing project has different LVRs to different respondents based on their value dynamics in a disaster. These observations highlight the fact that the LVR of a housing project in a disaster is influenced not only by the design of the project, but also by the dynamics of stakeholder values during such an event.

Table 4. LVRs of housing projects to stakeholders.

Respondents	VRs Before the disaster		VRs During the disaster		VRs After the disaster		LVRs	
	HP 1	HP 2	HP 1	HP 2	HP 1	HP 2	HP 1	HP 2
R1	0.811	0.327	0.485	0.511	0.826	0.376	1.314	-0.711
R2	0.362	0.600	0.251	0.140	0.362	0.231	0.447	1.657
R3	0.828	0.511	0.551	0.382	0.957	0.646	1.173	0.584
R4	0.890	0.672	0.230	0.242	0.666	0.688	2.529	1.728
R5	0.735	0.619	0.387	0.202	0.439	0.242	1.244	1.479
R6	0.792	0.759	0.502	0.365	0.898	0.831	1.214	1.613
R7	0.612	0.422	0.372	0.235	0.653	0.454	0.982	0.766
R8	0.554	0.320	0.375	0.146	0.636	0.292	0.757	0.681
R9	0.337	0.172	0.181	0.110	0.342	0.274	0.624	0.302
R10	0.767	0.510	0.459	0.321	1.283	1.085	1.491	1.044
R11	0.444	0.421	0.273	0.172	0.702	0.473	0.813	1.019
R12	0.636	0.427	0.402	0.176	0.611	0.361	0.926	0.974
R13	0.584	0.432	0.343	0.168	0.674	0.413	1.009	1.044
R14	1.047	0.773	0.441	0.294	1.335	1.128	2.567	2.094
R15	0.342	0.364	0.232	0.229	0.445	0.380	0.493	0.551
R16	0.646	0.757	0.505	0.521	1.113	1.131	0.797	1.129
R17	0.429	0.282	0.268	0.124	0.759	0.684	0.810	0.832
R18	0.423	0.156	0.289	0.225	0.892	1.036	0.770	0.163
R19	0.496	0.530	0.226	0.123	1.019	0.909	1.340	1.817
R20	0.641	0.456	0.112	0.167	0.949	0.677	2.268	1.267

CONCLUSIONS AND CONTRIBUTIONS

This paper proposes a resilience evaluation framework (SVD-RE) that integrates stakeholder value systems and dynamics with resilience evaluation. The application of the SVD-RE framework is demonstrated using a hypothetical case study where VRs of two alternative housing projects are measured and compared. This research proposes a new model that systematically solicits, integrates, and aligns human values with engineering design. It offers mathematical modeling of human factors by measuring the contribution of a resilience asset to stakeholder value fulfillment, the alignment between value fulfillment and stakeholder value priorities, as well as the dynamic change of stakeholder value priorities in a disaster. The proposed model effectively incorporates the human element/perspective with resilience evaluation, thus guiding community resilience decision making in a systematic manner. It uniquely incorporates human perspectives into housing resilience assessment, facilitating human-centric resilience designs/strategies that maximize the value to the stakeholders based on their priorities.

LIMITATIONS AND FUTURE WORK

While this research provides a new resilience evaluation framework that integrates stakeholder value dynamics, there are several limitations that suggest the need for future study. The experimental case study is conducted in a hypothetical disaster with limited number of stakeholders as well as selected stakeholder values. This study, while demonstrative, assumes uniform hurricane intensity across different neighborhoods and does not consider how these differences might affect the responses to the survey, potentially overlooking variations in local risk factors and their impact on stakeholder value assessments. Future research should focus on employing the framework to examine the resilience of different types of resilience assets under various real disaster scenarios, with a larger number of stakeholders involved. This work together with the future work will advance our understanding on how to quantify and analyze the value that a resilience asset offers, and they will provide a foundation for understanding how to plan and design communities in a way that maximizes its collective resilience value to the stakeholders.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation (NSF) under Grant No. 1933345 and No. 2325467. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

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