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Abstract
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Keywords
Post-disaster housing recovery, system dynamics, social vulnerability, causal factors, indicators

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An Interdisciplinary System Dynamics Model for Post-Disaster Housing Recovery

Elaina J. Sutley, Ph.D.[1] and Sara Hamideh, Ph.D.[2]

Abstract

Many previous disasters have demonstrated the need for extensive personal, public, and governmental expenditures for housing recovery. In fact, the share of housing in community recovery and the extensive financial reinvestment from individuals and the government required for restoring a damaged housing sector highlight the importance of studying housing recovery. Yet, much research is still needed to fully understand the multi-faceted and complex nature of housing recovery. The goal of this paper is to present a holistic model to further the understanding of the dynamic processes and interdependencies of housing recovery. The impetus for this work is that inequalities in housing recovery could be addressed more effectively if we better understood interconnected factors and dynamic processes that slow down recovery for some. Currently, there is a lack of understanding about such factors and processes. Literature from engineering and social sciences was reviewed to develop an integrated system dynamics model for post-disaster housing recovery. While it is beyond current capabilities to quantify such complexities, the presented model takes a major stride towards articulating the complex phenomenon that is housing recovery.

Keywords: Post-Disaster Housing Recovery; System Dynamics; Social Vulnerability; Causal Factors; Indicators

Introduction

Housing is a major sector of the United States' physical building infrastructure, financial infrastructure, and social infrastructure (Comerio, 1997). Buildings used for housing represent the highest percentage of all buildings in the United States, and this holds true at the state, county, and local scales (Comerio, 1997). From an economic perspective, a home is generally a household's largest financial investment. From a resilience perspective, housing damage and relocation make up a significant portion of disaster losses (Peacock, Van Zandt, Zhang, & Highfield, 2014) and reestablishing housing is a crucial part of community recovery (Peacock, Dash, & Zhang, 2007) and especially critical for the recovery of vulnerable populations like children (Fothergill and Peek, 2015). Many previous disasters have demonstrated the need for extensive personal, public, and governmental expenditures for housing recovery. For example, Reitherman and Cobeen (2003) reported that approximately half ($20 billion) of the property loss caused by the 1994 Northridge Earthquake was due to damage to residential wood-frame buildings. Similarly after Hurricane Andrew, Zhang and Peacock (2010) reported that nearly $11 billion out of $26.5 billion in total losses were distributed to homeowners through insurance settlements for housing reconstruction. These two examples represent the common case. The share of housing in overall recovery and the extensive financial reinvestment required for a damaged housing sector from individuals and the government highlight the importance of studying housing recovery.

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While there is a growing agreement on the complexity of housing recovery (Alesch, Arendt, & Holly 2001 and others[1]), its dynamic processes and interdependencies have rarely been modeled. Dynamics of political, social, and economic processes at all of the spatial scales (housing unit, neighborhood, community, state, and national) influence the directions of the post-disaster reconstruction and highlight a critical need for understanding and measuring recovery outcomes resulting from such processes (Johnson & Hayashi, 2012). This paper presents a model we developed to explain and further the understanding of the dynamic processes and interdependencies of housing recovery. By better understanding the processes and interdependencies, interventions, such as structural and non-structural mitigation and recovery assistance programs, can be enhanced to improve the resilience of housing, and thereby improving a community's resilience.

Many researchers have quantified and modeled housing recovery, but still no study has been conducted that exclusively models the process of housing recovery from a holistic perspective. Differential housing recovery within a community results from differential exposure, social vulnerability (Cutter, Schumann, & Emrich, 2014; Peacock, Van Zandt, Zhang, & Highfield, 2014; Zhang & Peacock, 2010), and myriad other factors, including differential infrastructure quality, which is often linked with social vulnerability (Van Zandt & Sloan, 2017). The motivation behind our model is that inequalities in housing recovery could be reduced if we better understood factors and processes that slow down recovery for some. Currently, there is a lack of information on such factors and processes. The objectives of this paper are to model the housing recovery system and the dynamic features in its interdependencies and to provide a framework to investigate policies and mitigation strategies that address social vulnerability. Two main bodies of literature support the present study. The first of these are quantitative engineering studies that have modeled post-disaster housing recovery. The second are quantitative and qualitative social science studies which have measured post-disaster housing recovery or examined associated disparities. The literature on modeling studies provides the background for the present model which builds upon and offers an advancement upon the previous work. The literature on recovery measurement and statistical studies were used to identify the necessary variables for the present model.[2] The model presented here takes an interdisciplinary approach by applying causal factors examined by social scientists in an engineering model to deepen understanding of post-disaster housing recovery. While it is beyond current capabilities to quantify such complexities, the presented model takes a major stride towards articulating the complex phenomenon that is housing recovery.

Existing Housing Recovery Models and Their Findings

When a community is recovering from a disaster, there are several goals in designing the steps toward housing recovery. For example, cost, quality, speed, accessibility, resident satisfaction, and future resident safety are a few of the criteria which set these goals. When developing the specific structural solutions, material availability and culturally-sensitive designs are additional criteria. These criteria and goals represent many of the variables and objectives in the existing housing recovery models. In engineering studies, housing recovery models are based on data from previous disasters to understand and predict the recovery process, recovery outcomes, or the overall recovery time. These models aim to provide risk-information for better decision making through the ability to investigate interventions such as planning and policies, or incorporate decision-maker preferences into selecting interventions based on tradeoffs between initial investment and social cost. Housing recovery models need to include as many variables and subsystems as self-evident to guarantee accuracy in the results. The existing models related to housing recovery include optimization algorithms, genetic algorithms, agent based models, and system dynamics models. Each of these has their own pros and cons which often are dependent on the problem being modeled. The existing models provide isolated pieces of the recovery system that individually examine labor supply, material supply, temporary housing, government plans, or household decisions. Our model is intended to simulate the bigger picture of housing recovery and provide a holistic approach that incorporates the interdependencies of the system and the isolated pieces previously modeled.

The housing recovery process can be divided into several stages. For example, the seminal work by Quarantelli (1982) offers four stages: emergency shelter, temporary shelter, temporary housing, and long-term housing. These four stages are often progressive and can be assigned timelines using data from previous disasters. The stages and associated timelines are also non-linear, overlapping, are dependent on myriad factors that vary significantly across households with different levels of social vulnerability. These factors include outcomes in the previous stages and plans for the next stage. In 2010, El-Anwar investigated alternative temporary housing solutions in the aftermath of natural disasters. The purpose of the study was to identify temporary housing solutions that improved the environmental, social, economic, and public safety impacts on the community. The research question was modeled as a single-objective optimization problem that maximized the net social benefit, and solved via weighted integer programming. The social benefits were measured using the outcomes of previous efforts of El-Anwar and colleagues (El-Anwar, El-Rayes, & Elnashai, 2008; El-Anwar, El-Rayes, & Elnashai, 2010a and 2010b) that developed indices for employment and education opportunities at the housing locations, housing quality, housing delivery time, capacity of temporary housing location to support healthcare and safety needs for displaced families, and access to public transportation and essential utilities and services. Later, in 2013, El-Anwar compared integer programming and genetic algorithms for modeling hybrid housing development plans based on effectiveness, efficiency, and robustness. The hybrid housing development plans were part of a FEMA-initiated alternative housing program aimed at speeding up and smoothing out the transition from temporary housing to long-term housing. The alternative housing program was piloted in the Gulf Coast states following Hurricanes Katrina and Rita. In El-Anwar's analysis, the genetic algorithm demonstrated higher modeling flexibility, however the integer programming demonstrated superior performance in its ability to find the true optimal solution in fewer iterations. These investigations suggest that for better recovery, temporary housing developments must have access to transportation, employment, education, and healthcare. Their body of work provides insight into temporary housing, and many of the variables that need to be considered, namely accessibility, for long-term housing recovery.

Other studies have also demonstrated the importance of providing access to the most basic community services (Bolin, 1982; Bolin & Bolton, 1986; Golec, 1983; Lizarralde, Johnson & Davidson, 2003) as well as keeping neighbors and friends near each other during temporary housing (Erikson, 1982). In 2014, Rakes, Deane, Rees, and Fetter developed a decision support system using integer programming for assigning families to temporary housing units. The integer programming model served as a benchmark for the decision support system development, and produced results identifying housing assignments at a neighborhood level, rather than individual household basis. The model identified housing assignments by minimizing the distance between families with their preferred neighborhood and necessary support services, such as schools and healthcare. However, since families look for alternative housing on a unit basis, and not a neighborhood basis, the integer programming solution(s) could not be used in real-time. The authors investigated three heuristics to overcome the lack of data at the time of solution finding so that the results could be used in real-time. The heuristics focused on housing unit size, socioeconomic distance, and a combination of the two. The “best’ heuristic was identified by offering the best balance in its solution. These works suggested types and locations of temporary housing structures that promoted recovery. A critical piece into our model was added based upon these authors’ emphasis that housing recovery is related to household recovery, and one way to measure this is through neighborhood recovery.

Oftentimes, permanent housing reconstruction takes place simultaneously with temporary housing. The reconstruction of housing units is a system in and of itself, similarly, as is temporary housing. Before reconstruction can begin for any particular housing unit, the owner has to make the decision to rebuild. That decision and its timing can be based on land-use policy changes following the disaster, the owner’s financial resources and connection to the neighborhood and community, policies related to recovery assistance, and the decision made for surrounding housing units, among other factors. To investigate homeowner decision-making, Nejat and Damnjanovic (2012) applied agent based modeling. Their multi-agent system model simulated housing recovery using homeowners as intelligent agents. The simulation results revealed cluster formulation (groups of households deciding to start reconstruction at the same time) to be an emergent phenomenon during recovery, a result identified by the temporal-spatial capability of the model. The results also demonstrated that increasing the discount factor (costs incurred while waiting to decide to rebuild) in situations with low uncertainty resulted in a faster rate of reconstruction. Only single-family owner-occupied residences and the owner’s decisions were considered in the model, and outside influences such as the public sector and availability of infrastructure, were beyond the scope. This work further demonstrated the connection of housing recovery to household recovery, and gave us insight into the importance of decision making as a variable in measuring the time required for reconstruction and recovery, and the role of neighbors’ and friends’ decisions to rebuild.

After the decision to rebuild has been made, the logistics of this decision become paramount. The housing unit must be accessible, the debris must be cleared, materials must be available, and there must be a labor supply. For example, in the case of severe floods in Lumberton, North Carolina following 2016 Hurricane Matthew, many residents were unable to get to their home to start repairs or removal of contents for several days until flood water subsided on roads.[3] Two studies have explicitly investigated some of these logistics, both through system dynamics stock management models. In 2015, Diaz, Kumar, and Behr (2015) applied a system dynamics stock management model from a material resources perspective for modeling housing recovery. The specific system being modeled was the construction material supply system. It included two negative feedback loops: one for the material stock-out loop, and one for the material control loop. Material inventory was modeled as a stock based on the material delivery rate and the material usage rate. From their material resources perspective, the worst case scenario was found as a situation to which housing production stopped due to a nonexistent material inventory. Their model demonstrated that the reconstruction process, and therefore the time for reconstruction to be completed, was influenced by the flow of capital to the afflicted area, fluctuations in materials, and the number of reconstructed houses assigned to disaster victims. Kumar, Diaz, Behr, and Toba (2015) employed a system dynamics stock management model to analyze the impacts of a disaster on labor supply for housing recovery and rebuilding in a devastated region. The system being modeled was labor management, and it included internal feedback loops and time delays which captured the consequences of the decision to recruit additional labor force in a post-disaster reconstruction scenario. There were two main loops, one for post-disaster construction job vacancy creation, and one for post-disaster labor adjustment. Post-disaster labor and post-disaster job vacancy were modeled as stocks that increased or decreased based on the post-disaster job vacancy creation rate, the job vacancy closure rate, the job cancellation rate, the hiring rate, the quit rate and the layoff rate. Their model demonstrated the importance in the awareness of delays as well as the flexibility in the work schedule in the design of housing construction and hiring policies to improve recovery. Together, the two studies gave us insight into the significance of accessibility to the house for reconstruction purposes, and the significance of construction material and labor supply availability.

The above discussion on existing models provides insight into the types of models that have and can be used for modeling housing recovery, and on the interactions of temporary housing, reconstruction decision-making, and construction material and labor supply when rebuilding permanent housing. There are many additional dependent and interdependent factors to consider, including the influence of the recovery of other infrastructure systems on housing recovery. One approach to investigating these additional factors is through modeling the community recovery process. In 2014, Hwang, Park, Lee, Lee, and Kim applied a system dynamics model to investigate post-disaster community recovery. A causal loop diagram was used to capture the feedback processes across the interdependent restoration operations across community sectors (e.g., residential and commercial buildings, critical facilities, industrial facilities, transportation infrastructures, and debris clearance and disposal). The intention of the causal loop diagram was to quantify the effect of government plans for specific community sectors on the recovery system. The model investigated the recovery implications for the community when resources were allocated differentially to the various community sectors. The model was specifically designed for a case study of the 2011 earthquake in Tohoku, Japan. It was not specific to housing recovery, however, it was designed to be somewhat scalable to the community-sector level, and with additional investigation it could be extended to other disaster scenarios. Ultimately, their model demonstrated that resources have to be distributed across all sectors in a parallel recovery effort for the quickest community-level recovery. It gave us insight into how we could include other infrastructure systems in our model, the significance of those infrastructure systems in housing recovery, and a better picture for how housing fits into overall community recovery.

While we gained a lot from surveying the existing housing recovery models in the engineering literature, we came to two conclusions. First, there is no one-size-fits-all solution for modeling housing recovery. We selected a system dynamics model for explicating housing recovery based on the ability of this model to visually display the interdependencies of this complex system. Second, there are a number of factors that were left outside of the scope of the existing models. Thus, we looked to the social sciences to help us better identify the breadth of causal factors.

Indicators for Housing Recovery

This review provides an extensive list of causal factors and indicators of housing recovery discovered in the literature. Causal factors help explain the disparities in recovery outcomes. Indicators are a more specific form of metric which specify stages in a process. The purpose of this review was to uncover explaining variables to inform our housing recovery model. The reviewed studies used qualitative and quantitative data collected through surveys, structured interviews, and secondary data such as building permits, aerial imagery, tax appraisals, and census data. A combination of data types were often used in a single study to measure the progress, or explain disparities in recovery. Measurements were sometimes specific by only including a single element, such as the restoration of improvement value based on tax appraisals. The identified indicators and causal factors were categorized as initial impact and emergency response, temporary shelter and temporary housing, physical damage and reconstruction of long-term housing, the impacted population, financial resources, and recovery policies and planning. Our intention was to uncover as many indicators and casual factors as possible from the literature, then use their given context to discern which were necessary for us to capture in our model.

The time of day that a disaster occurs can impact how emergency response and recovery will take place. For example, the 2004 Niigata Ken Chuetsu earthquake occurred in the early evening followed by many landslides and aftershocks and 13 hours of darkness. Because of the time of the earthquake, emergency response was limited, and the extent of the damage was unknown until daylight (Olshansky, Nakabayashi, & Ohnishi, 2006). After the extent of the impact is known, a state or federal disaster declaration may be made which can then be used as an indicator of the progress along the timeline of recovery, and an indicator of the severity of the impact (Rossetto et al., 2014). The distance of a community or neighborhood from the most severely impacted area can also be an indicator for how long it will take for housing to recover (Weber & Lichtenstein, 2015). We found these specific variables to be outside of the scope for our model. These are very useful measures for setting the initial context and determining when a disaster occurs, however, we chose to focus our model around the permanent housing phase, and let these variables show through the context of what proceeded the disaster declaration but preceded the long-term housing phase.

Following initial impact and emergency response comes temporary shelter and temporary housing. The number of temporary shelters relative to the population size (Paul & Che, 2011 and others[4]), and the quality of temporary shelters (Boano, 2009) can be used for predicting recovery across a community. As the recovery timeline transitions into temporary and long-term housing, the presence of temporary shelters in only a portion of neighborhoods can be an indicator of differential recovery (Liel et al., 2013). The number or percentage of residents living in temporary housing (Tafti & Tomlinson, 2014; Boano, 2009; Hwang, 2011; Mitchell et al., 2012), the location of the temporary housing (Paul & Che, 2011; Green, Bates, & Smyth, 2007), the time spent in temporary housing (Paul & Che, 2011), and the type of temporary housing (Rathfon et al., 2013) can also indicate the progress of housing recovery. These variables gave us specific motivation to develop a scalable model which would be able to capture disparities across a community. Ultimately, we concluded from the literature that the type of temporary housing accommodation and time spent in temporary housing were critical factors in the decision making time and outcomes for housing recovery.

The level of damage to each residential building (Comerio, 2006 and others[5]), the completion of the damage assessments (Olshansky et al., 2006), the resulting cost of repairs (Kamel, 2012), and the amount of time required for repairs (Comerio, 2006; Francisco, 2015; Wu & Lindell, 2004) are indicators of the progress of housing recovery. Oftentimes before reconstruction can begin, debris must be removed, and thus the extent of debris removal can be used as an initial indicator of recovery progress (Green et al., 2007 and others[6]). Several studies indicated that post-disaster reconstruction is an indicator of housing recovery (Arlikatti & Andrew, 2012 and others[7]). Various metrics were used, including the formulation and completion of a reconstruction plan (Siembieda et al., 2012), any resulting reconstruction policies (Liel et al., 2013), and the rate and distribution of reconstruction (Paul & Che, 2011). Reconstruction was also linked to new building permits. Several studies investigated spatial and temporal patterns of new building permits to monitor recovery or differential recovery (Cui, Daan, & Ewing, 2015 and others[8]). In efforts to promote reconstruction, and equitable reconstruction, impacted communities often adopt temporary policies for speeding up the process for issuing building permits by relaxing some of the costs, regulations, and procedures. This is especially helpful in communities where the local familial culture includes passing a house down to the next generation in an informal manner. Altering building permit costs, regulations and procedures were identified as factors in the rate of reconstruction (Hwang, 2011; Rossetto et al., 2014). Consequently, issuance of occupancy permits is an indicator of the completion of the reconstruction process (Green et al., 2007; Rathfon et al., 2013). It must be acknowledged that issuing permits faster, and speeding through reconstruction, is not a guarantee for successful or resilient recovery since this can ignore cultural preferences in architectural designs, force people to move to unwanted areas, and can promote problematic construction practices. Even still, the resulting total number of new units (Cheng et al., 2015), specifically the number of single-family homes (Dash, Morrow, Mainster, & Cunningham, 2007), and the change in the number of housing units (Dash et al., 2007 and others[9])) have been used as indicators for determining how well a community's housing system has recovered. More broadly, population return (Paul & Che, 2011; Green et al., 2007; Mitchell et al., 2012) and growth (Lui & Plyer, 2008 and others[10]), and the overall community growth pattern (Wright, Rossi, Wright, & Weber-Burdin, 1979) were used as indicators of the severity of the impact on the population, and its recovery. We have adopted many of these measures into our model, specifically how building permits influence repair rates, and how policies impact issuance of building permits. The authors caution here that while these can all be good measures, and while completion of housing reconstruction is a necessary task for housing recovery, the speed to which reconstruction is completed is a double-edge sword type of metric, and many other criteria must be considered. Taking excessive amounts of time to reconstruct housing certainly inhibits the community's ability to recover. However, a hastily-developed plan for reconstruction can lead to re-adoption of the pre-disaster vulnerabilities.

Several social science studies have shown income and poverty, race and ethnicity, gender, age, housing tenure status, education, religion, and social isolation as factors of social vulnerability (Fothergill, 1999; Cutter, Boruff, & Shirley, 2003) that influence where people live before disasters (both location and housing type), the extent of damage to their property, their access to social, economic, and political resources, and therefore their ability to recover from disaster impacts (Van Zandt et al., 2012; Sapat & Esnard, 2017). The housing recovery literature has specifically discussed tenure status (Mukherji, 2010; Lowe, 2012), income level (Peacock et al., 2007 and others[11]), social capital (Francisco, 2015), the distribution of the population by race (Green et al., 2013; Peacock et al., 2014), and the percent of immigrant population (Nguyen & Salvesen, 2014) as factors influencing housing recovery. For example, it has been argued that if there is an immigrant population, then the cultural competence of recovery assistance personnel will be important, otherwise, differential (slower) housing recovery can be expected for the immigrant population (Nguyen, 2014; Hwang, 2011). This portion of the literature gave us significant insight to include aspects of social vulnerability and its influence on the pre-disaster state, the post-disaster available resources, and the differential result of policies.

The amount of money flowing into a disaster impacted area varies remarkably taking many forms across different scales. The amount of financial resources made available to the community, businesses, and households is critical for predicting recovery. Specific features of financial resources, including the amount and type of funds available to a household (FEMA assistance, SBA loan, personal savings, insurance, lending from friends or family) can be used as causal factors determining outcomes of recovery (Simon, Arlikatti, Long, & Kendra, 2013 and others[12]). Housing recovery is inherently tied to the housing market economy. The recovery of the housing market can be measured through indicators, including the ratio of buildings to vacant land pre- and post-disaster (Hoshi et al., 2014), or the density of housing (Stevenson et al., 2013), comparisons between the pre-event and post-event vacancy rates (Zhang, 2012), the changes in assessed property value (Peacock et al., 2014; Weber & Lichtenstein, 2015; Zhang & Peacock, 2010), the number of people selling their home (Green, 2012; Rathfon et al., 2013; Zhang & Peacock, 2010), the number and percentage of foreclosure notices (Weber & Lichtenstein, 2015; Brown et al., 2012), abandonment (Peacock et al., 2014), eminent domain policy (Paul & Che, 2011), and the pre-disaster versus post-disaster number of rent controlled apartments and rent prices (Kamel, 2012). These studies provide insights on how to include various forms of financial resources and their influence on repair rates. They also establish the significance of including improvement value as a necessary indicator of housing market economic recovery, as well as an indirect measure for reconstruction progress. Accessed improvement value is publically assessable data that sometimes comes in a package with property value, geospatial foreclosure notices, tenure status, and indicators for abandonment (whether taxes are being paid). This tax assessor data does not require high-elevation vantage points or expensive technical equipment to capture or process the data. We have designed the model to be expandable to include additional measures if the user has other datasets available to them.

In the midst of disaster response and recovery, new policies are often enacted to help guide the process. Sometimes these policies are temporary, and other times they become permanent. The policies vary across time and space, and the types of policies that are enacted can be used as causal factors for housing recovery. For example, during the temporary shelter and temporary housing phases, temporary policies can be enacted for free rent to dislocated households (Paul & Che, 2011). In the rebuilding phase, there can be policies regarding the contributions given by the various levels of government (Rossetto et al., 2014), new land use (Hwang, Park, Lee, Lee, & Kim, 2011), and land acquisition policies (Wachtendorf, Kendra, Rodriguez, & Trainor, 2006). When land use and land acquisition policies are enacted, if land is taken away, then it is less likely that the community will reach its pre-disaster population numbers. In the immediate aftermath, as well as after the bulk of the recovery is complete, new disaster management policies are also often adopted based on lessons learned (Mitchell et al., 2012; Kamel, 2012; Taft & Tomlinson, 2015). Following disasters a critical window of opportunity opens for enacting new hazard vulnerability reduction plans and policies. Having hazard mitigation plans in place, and more specifically having higher quality proactive hazard mitigation plans in place, should lead to more long-term vulnerability reduction in post-disaster decision-making by allowing the post-disaster window of opportunity to be capitalized (Godschalk, Brower, & Beatley, 1989; Smith & Wenger, 2007; Smith, 2012; Berke, Lyles, & Smith, 2014). When marking recovery, the existence of higher level recovery plans (Hwang, 2011; Lu & Xu, 2014) can be an indicator to how recovery will occur. Additionally, it has been shown that community members involvement in recovery planning (Landenback & Dusi, 2004), coordination among non-government organizations (NGOs) (Wachtendorf et al., 2006; Boano, 2009), and community access to information regarding shelter locations, road access, and recovery planning meeting times and locations, for example, during recovery (Francisco, 2015) leads to a healthier recovery (Comerio, 2017). Policies play a pivotal role in housing recovery. Based on this literature we have included a breath of policies interacting with multiple facets of the housing recovery system.

Housing is only one community sector that is connected to education, healthcare, commerce, governance, religious, and cultural sectors, among others. It has been shown that school enrollment (Lui & Plyer, 2008) and attendance (Liel et al., 2013), availability of healthcare, retail, and food services (Rossetto et al., 2014; Paul & Che, 2011) can be used as causal factors for housing recovery. Xiao and Van Zandt (2012) reported a close link between housing recovery and business recovery. We include all of these through a variable termed accessibility.

The reviewed studies from both disciplines identified elements that affect the housing recovery process. These elements became the necessary variables in the housing recovery model presented in the next section. While the variables listed were comprehensive, the presented model is simplified in order to conceptually present the capabilities of a stock and flow system dynamics model, but also to emphasize the most critical causal factors. Ultimately, consideration of the end user and their access to specific data aided in this process. All variables included in the model were identified to be critical for explaining and modeling housing recovery due to the extent and content of their presence in the literature.

An Interdisciplinary Housing Recovery Model

A system dynamics model captures the dynamic nature in the interdependencies of a system and enables the investigation of interventions that could change the dynamics of that system. A stock and flow system dynamics model is introduced here, where "stock and flow" specifies the type of system dynamics model. The stock and flow model is applied to the housing recovery system, and henceforth referred to as our "housing recovery model." The proposed housing recovery model integrates engineering and social science perspectives on post-disaster housing recovery. The previous section reviewed studies from both disciplines which identified elements that affected the housing recovery process. These elements became the necessary variables in the housing recovery model presented in this section.

A stock and flow model was selected here for explicating housing recovery because it provides a visual representation of the relationship between different elements within a housing recovery system. This depiction can increase current understanding on the interaction of the dependencies and interdependencies, and how they relate to the housing recovery process. Our model is designed to be hazard-generic, and is thus applicable across all types of disasters. The model is also designed to be scalable, and thus is applicable at the community, neighborhood, and single housing unit level. When in use, however, many of the inputs should be hazard-specific and at a consistent scale. At the community-level, the ultimate goal of the housing recovery model is to provide a depiction of the complex system that can be used for improving overall housing recovery for a community. This could be accomplished through applying the model to investigate the implications of policies and structural mitigation interventions enacted before the disaster, and at different stages after the disaster. Similarly, at the neighborhood and single housing unit levels, the model can provide a platform for improving housing recovery by investigating the implications of pre-disaster vulnerabilities, structural mitigation interventions, and recovery policies at the respective scale. Neighborhood level analyses can investigate differential recovery across neighborhoods. Single-housing unit-level analyses can investigate differential recovery across housing units within a neighborhood, and the impact of recovery policies and interventions on such disparities.

A stock and flow model has three categories of elements, namely stocks, flows, and supporting variables. The stocks are capacities in the system that increase or decrease during the dynamic process. The flows are the rates that determine the amount of increase or decrease in the stocks. The supporting variables are the other variables necessary for modeling the stocks and flows. The elements within each of these three categories are provided in the following sub-sections. First, a simple closed loop stock and flow model of housing reconstruction is shown in Figure 1 and discussed to demonstrate the mechanics of such a model. In Figure 1, there are two stocks, *Building Stock Quality* and *Damage*, and there are two flows, *Damage Rate* and *Repair Rate*. The *Building Stock Quality* decreases as the *Damage Rate* flows, and increases as the *Repair Rate* flows. Similarly, the *Damage* increases as the *Damage Rate* flows, and decreases as the *Repair Rate* flows. A disturbance is required to initiate movement in the system. Indeed, there are many variables that influence each of the four elements in Figure 1, and the necessary variables for explaining the four elements depend on how the elements are defined and measured.

The housing recovery process consists of much more than the reconstruction of housing units. Therefore, the model in Figure 1 needs to be expanded. Figure 2 provides a simplified stock and flow model for housing recovery which includes a third stock, *Available Resources*, a third rate, *Repair Resource Allocation Rate*, as well as an element for *Social Vulnerability*, *Delay Time*, and elements demonstrating the breadth and importance of *Policies* in many facets of housing recovery. As shown in the legends of Figures 1 and 2, boxed elements are expandable; elements with double lined arrows coming out are stocks; elements next to valves are flows; and elements connected to single lined blue arrows are supporting variables. *Social Vulnerability* was added as the key supporting variable for addressing the objective of this study. A community's, neighborhood's, and household's social vulnerability can influence their access to available resources. The residential building quality is also dependent on the social vulnerability of the community, neighborhood, or single housing unit being modeled (Zhang & Peacock, 2010; City and County of San Francisco, California, 2016). Locations of housing units are also often affected by social vulnerability, where more socially vulnerable households live closer to locations which are more susceptible to hazards (e.g., floodplains) (Highfield, Peacock, & Van Zandt, 2014). Access to resources, building quality, and building location can be linked, and can be cascading. Persons and households with higher social vulnerability are often times renters. Renters in general have a lower access to resources before and after disasters as many incentive programs are designed around homeowners, and many recovery fund programs are designed around homeowners. Comerio's (1998) cross-disaster comparative analysis suggested that the focus of housing recovery policy in the United States on single-family owner occupied housing plays an important role in shaping inequalities in housing recovery, particularly with respect to rental and multifamily housing. Furthermore, socially vulnerable households have fewer financial resources, and therefore live in government assisted housing which is sometimes of poorer quality (City and County of San Francisco, California, 2016). The cascading impact occurs when the lower quality housing is occupied by a household with fewer resources, and is in a physical location that is more susceptible to damage and thus exacerbates the differential impact and ability to recover. Thus it is clear that including social vulnerability in the model becomes a necessity.

Referring back to Figure 2, the *Repair Rate* is a function of a *Delay Time* needed for contract procurement, design time, building permit issuance time, decision-making time, and more (Mitrani-Reiser, 2005). The *Repair Rate* is also dependent on the supply of resources, hence its connection to the *Repair Resource Allocation Rate*. After Hurricane Katrina, for example, rebuilding slowed due to the lack of availability of needed resources (Nelson, Ehrenfeucht, & Laska, 2007).

Stocks

The model in Figure 2 consists of three stocks which are broadly named and enclosed by an outline. As mentioned earlier, the outline implies expandability. Figure 3 provides a partially expanded stock and flow model of housing recovery with the additional measures included as stocks. For example, the *Building Stock Quality* can be measured by a number of variables, including the *Structural Integrity*, *Functionality*, the tax assessed *Improvement Value*, and the *Accessibility*. Each of these can be further expanded, if desired. For example, structural integrity can be measured by the design quality, level of damage, or progress in repair. Functionality has overlap with structural integrity, but here can be expanded, as shown in Figure 4a, to include the restoration of utilities – which are systems in themselves, and resumption of occupancy – an indicator of housing recovery.

Figure 4b shows the expansion of accessibility to include the quality of roadways, debris clearance, and an example of a potential hazard-specific measure, flood level. For a different hazard, earthquake for example, there may not be a hazard-specific measure. These variables represent physical obstructions limiting accessibility. Figure 4b also provides variables demonstrating the breadth of this critical stock, namely, access to healthcare, employment, community services, childcare and education, and noting that this is still not a complete list of the critical services and community sectors that a successful housing system needs to access. We consider accessibility variables in terms of how they impact recovery of housing. For example if there is limited access to employment in a community hit by a disaster, homeowners may not start repairing houses, thereby postponing housing recovery, until employment and wages are accessed. This would also have an impact on household recovery. For example, if there is limited access to employment in a neighborhood after a disaster, this affects households' recovery not only in terms of housing but it can also increase transportation costs to get to jobs or make commutes longer, or even worse, residents of those houses may lose their job because of the limited accessibility. Accessibility further demonstrates one of the assets of the stock and flow model: ability to easily add, or otherwise alter, elements. It must be noted that Figures 1 and 2 were modeled in the dynamic systems modeling software Vensim PLE; the expanded model shown in Figure 3 was not modeled in Vensim PLE to increase readability.

Similar to functionality and accessibility, *Damage* can be expanded to include specific stocks relating to each of the building stock quality stocks, as shown in Figure 5. In this way, damage to structural integrity could be specified as the percentage of permanent housing units needing repair, which can further be expanded to include the degree of damage (for example complete, extensive, moderate, and minor) if warranted by the scale of the analysis. Damage to functionality could be expressed as loss in functionality; damage to improvement value could be expressed as change in improvement value; and damage to accessibility could be expressed as loss in accessibility. These specific damage stocks can also be further expanded, as shown in Figure 5.

There are many types of *Available Resources* that are important for housing recovery, including *Personal Savings*, *Insurance Money*, *Financial Assistance*, and *Labor Supply*. This first level of expansion is provided in Figure 3, and Figure 6 provides a second level expansion for financial assistance and labor supply. Financial assistance can be further expanded to include the various financial resources that appear after a disruption, including the Federal Emergency Management

Agency's (FEMA) Minimal Home Repair (MHR) grants, Small Business Administration (SBA) loans, and Department of Housing and Urban Development (HUD) Community Development Block Grants-Disaster Recovery (CDBG-DR) funds. Labor supply can be expanded to include the specific labor supply that goes into the various work being done, including rebuilding, debris removal, and utility restoration. Of course, there are other sources of labor supply required for housing recovery, such as the labor supply to healthcare facilities, and the labor supply for business recovery which has an interdependent relationship with stable housing and housing recovery.

The stocks can continue to be modified or expanded to include as many measures of interest that still fall under the categories of *Building Stock Quality*, *Damage*, and *Available Resources*. The only constraints are that in order to be incorporated into the model, the measures should be necessary since unnecessary measures only add noise to the model. The measures should also be directional, meaning that they must increase or decrease in value (Albin, 1997). Moreover, stocks should be time dependent, whether binary variables that switch on and off like electric power outage at the single housing unit scale, or a time series that has a value varying between 0 and 1, or even exceeding 1. It is critical for the time series to measure the stock both pre- and post-disruption in order to get an in-depth look at the entire housing recovery process so that the model is applicable both with and without the disruption. This is necessary for understanding of the housing recovery process, understanding when policies may be most effective if enacted, and understanding how interventions will affect the entire timeline.

Flows

Figure 3 shows three expandable flows: *Damage Rate*, *Repair Resource Allocation Rate*, and *Repair Rate*. Damage rate and repair rate go hand in hand, and can be expanded to specific measures for each stock shown in Figure 5. Repair resource allocation rate can similarly be expanded for each available resource shown in Figure 6. All of the flows can be specifically defined, but must remain time-variant, and must change the value (increase or decrease) of the connecting stock(s) (Albin, 1997). The flows were left unexpanded in Figure 3 for readability, but when expanding the flows, their arrows should be drawn for each stock and each flow separately.

Supporting Variables

The supporting variables provided in Figure 2 include *Social Vulnerability*, *Hazard Type, Intensity and Exposure*, *Delay Time*, and *Policies*. Figure 3 further expands social vulnerability and delay time. There are still a number of additional variables needed for quantifying the housing recovery system shown and discussed in Figures 3 to 6. For example, *Structural Integrity* and *Improvement Value* are dependent on the age of the structure as well as specific features of the building, such as the size, number of stories, and type of structural material. *Accessibility* is expanded to include connecting roadways and access to community services. To accurately measure and account for these accessibilities, a significant number of supporting variables must be included. *Damage Rate* is dependent on the initial structural integrity and maintained quality of the building(s), as well as the type and intensity of the hazard, and the level of exposure. Furthermore, the ability of the damage rate to decrease the improvement value is partially dependent on the population change, the housing market dynamics, and zoning changes that could occur post-disaster. Delay time is shown in Figure 2 and expanded in Figure 3 to include time due to decision making, contract procurement, permit issuance, and building design. *Decision Making Delay* encompasses many variables, including the decision maker(s)' physical and mental health, decisions of other community members, or the neighbors, or friends, and available resources. Figure 7 provides an expanded version of decision making delay to emphasize the complexity of this supporting variable and its connection to physical and mental health, as well as temporary housing. Figure 7 shows that physical and mental health are based on many variables, including the type of temporary housing accommodation, and the time spent in temporary housing. For example, some Hurricane Katrina survivors stayed in FEMA trailers for as long as six years (Muskal, 2012). Merdjanoff (2015) reported that families that moved more frequently between temporary houses over a five year period after Hurricane Katrina experienced more severe mental health impacts. Following Hurricane Sandy, more homeowners with damaged residences opted to stay in their partially damaged homes with mold, rather than dislocating into temporary housing. It has been shown that partial damage to one's house can create more severe mental health impacts than complete damage. Choosing to live in a partially damaged home, especially if it had mold, can cause negative physical and mental health impacts, exacerbated by sustained exposure (NCDP, 2015).

Even still, this is a short list of the many supporting variables that can influence physical and mental health, decision making, and delay time. Many of the additional variables that are not shown here, and their impact on the repair rate, are often functions of the new or existing policies in place. In fact, Figure 3 provided three instances where our model integrated the role of *Policies* in the housing recovery system: policies acting on each of the *Available Resources* for housing recovery, policies acting on the *Repair Resource Allocation Rate*, and policies acting on the *Delay Time* variables. Policies are critical to understanding the housing recovery process, and understanding the speed in the housing recovery progress. Figure 8 provides an expanded view of some of the types of policies that might act on delay time and available resources. For example, recovery fund policies from FEMA restrict any money going to repairing damages that appear to have been caused by deferred maintenance (Henneberger, 2010; Van Zandt & Sloan, 2017). Disaster recovery has suffered from insurance policies which did not allow homes to be covered in flood zones (Burrus, Dumas, & Graham, 2011; Carter, 2014), insurance policies with anti-concurrent causation clauses (Lindell, Brody & Highfield, 2017), insurance policies which covered flood but not surge in hurricane-prone areas (Comerio, 2017), and policies which restricted recovery funds to homeowners who rebuild in the same location or rebuilt in a new location (McAneney, McAneney, Musulin, Walker, & Crompton, 2016).

There have been several instances of policy changes to speed up or regulate housing recovery. For example, after Hurricane Katrina, flood zones were re-mapped in New Orleans, and mitigation goals required homes located in the new flood zones to be elevated in order to qualify for federal flood insurance (Levine, Esnard & Sapat, 2007). Many people did not or were unable to afford the costs to follow this new regulation thereby maintaining their vulnerability to damage in future events, and hindering their ability to recover by not having insurance. At the same time, homeowners were settled in their permanent house faster. This highlights the complexities of policies and recovery, and the significance of investigating housing recovery at different scales, and from different perspectives. After Hurricane Ike, temporary policies were put in place to speed up the building permit issuance by waiving specific documentation of previous ownership (Van Zandt & Sloan, 2017). This recommendation was intended to reduce the disadvantage many low income residents faced when trying to start repairs to their homes. In that area, it was very common for families to remain in a single house for many generations, passing the ownership down informally and making it difficult for present generations to produce the necessary documentation for proof of ownership. Following the 2011 EF5 tornado that ravaged through Joplin, Missouri and after the earthquake in 1995 in Kobe, Japan, a moratorium was put into place to stop issuing building permits until a comprehensive recovery plan was developed (Phillips & Seeley, 2017; Hayashi, 2007). This type of regulation is often intended to insure that rebuilding does not reproduce the pre-disaster vulnerabilities, and allows lessons learned to be incorporated (Sapat, 2017), however, they also usually slow down rebuilding.

The types of recovery policies adopted following an event are highly dependent on the type and severity of the disaster. Our model is designed to be hazard-generic. However, the elements in Figures 3 to 8 with a dash-dot outline indicate the need for a hazard-specific input. Explicitly, Figures 4 to 8 do not provide this level of detail on all of the expanded elements for readability, however many of the shown elements in Figures 4 to 8 are also hazard-specific. Inputs such as *Policies*, *Structural Integrity*, and all subsets of *Available Resources* will be specific for the type of hazard, as well as the intensity of the hazard. For example, if a small flood occurs, it may or may not cause new policies for zoning changes. Conversely, with a major flood there might be a higher chance that zoning changes will be enacted post-disaster that could potentially trigger a lower rate of population return. Similarly, insurance companies have specific policies for the different types of hazards which must be included in the model inputs. The type and amount of external funding will depend on the type and size of the disaster as well. FEMA often provides MHR and HUD sometimes provides CDBG funds if an area with low to moderate income population has a national disaster declaration.

Model Outcomes

There are many measures of interest that a user could extract from the model and use as indicators of the progress and quality of housing recovery to help determine the impact of the policies and mitigation interventions. All of the elements modeled in Figure 3 might be of interest, and could be directly calculated and output from the model. Additionally, the resulting morbidities, including fatalities, physical injuries, and mental and emotional impacts, could be determined based on the percentage of permanent housing units in need of repair and the social vulnerability of the households (Sutley, van de Lindt, & Peek, 2016a and 2016b). An overall housing recovery time could be computed as the *Repair Rate* for all *Building Stock Quality* measures to return to or exceed their pre-disaster values, including the return of occupancy (see Figure 4a). When a community uses our model to plan for housing recovery, they can apply their agreed-upon goals and criteria for evaluating good recovery. Successful recovery has been defined in several different ways in the disaster literature such as returning to the pre-disaster state, returning to the counter-factual state, or restoring pre-disaster rates of change in any given measure of recovery. We have incorporated outcome variables that would allow for these different definitions of successful recovery. When quantified, our model provides flexibility to investigate different inputs to reach a range of desired outputs based on community goals and priorities.

The model provided in Figure 3, and expanded in Figures 4 to 8, is conceptual, but is intended to be quantified. The structural design level of the building stock can be modeled using performance and fragility curves (Sutley & van de Lindt, 2016), and the damage rate on the building stock, as well as the number of housing units in need of repair can be quantified using damage states and scenario analysis (Sutley et al., 2016a, 2016b). The improvement value can be measured using parcel-level tax data (Hamideh, Peacock, & Van Zandt, 2017). The delay time for repair rate can be adopted from previous works (Comerio, 2006; Mitrani-Reiser, 2005). Existing social vulnerability metrics and measurements can also be incorporated (Highfield et al., 2014, Van Zandt et al., 2012; Cutter et al., 2003; Sutley et al., 2016a). There are many public data sources available to researchers, or communities, to quantify those variables, and additional variables modeled in Figures 3 – 8. These public data sources and their relation to needed housing recovery variables are summarized in Table 1. Private data sources, such as personal banking accounts (which would provide useful information, but should always remain private), private insurance policies and payouts, and healthcare data, could also be used to further help quantify the existing available resources and the mental and physical health impacts. However, there are variables that have not been measured consistently and systematically, and require field studies, such as evacuation data, time spent in temporary housing, the type of temporary housing accommodation, and the influence of actions taken by neighbors and friends on individual decisions to rebuild or relocate. Some of this data has been collected through research studies for single events, as discussed in the above literature, but there is still much more to be collected and learned about those variables. Furthermore, while much of the data and variables needed for quantifying the housing recovery model in Figure 3 exist, as shown in Table 1, these variables have been quantified in isolation and not with interdependence. This presents but one restriction on the ability of the presented model to be fully quantified at this time. Another restriction is due to modeling limitations in the ability to capture qualitative relationships and interdependencies between human behavior and infrastructure systems, especially before, during, and after a disaster. Current interdependency models (e.g., Rinaldi, Peerenroom, & Kelly, 2001; Haimes, Horowitz, Lambert, Santos, Lian, & Crowther, 2005; He & Cha, 2017) analyze electric power systems, water distribution systems, and economic systems which have measured values associated with their interdependencies. These values are recorded and input into models with limited uncertainty. Such measured values do not exist for the interdependency relationships between social vulnerability and accessibility, for example, and this will be one of the major challenges for researchers in this line of study and will take extensive field work, including new techniques for field work, data collection and exchange between different fields, and new measurements. This complication extends to the need to integrate data at different spatial scales that is measured at inconsistent points in time. In our literature review, we explored the quantitative and qualitative works on housing recovery. Qualitative studies were used to deconstruct the interdependencies. In doing this, the true complexity of the housing recovery system became more visible by uncovering the multi-faceted and complex layers of housing recovery including policies, decision making and external aid stemming from households, NGOs, private companies and multiple levels of government. While it is beyond current capabilities to quantify such complexity, the presented model takes a major stride towards articulating the complex phenomenon that is housing recovery. The system dynamics model enabled us to examine the interdependent relationships and loops between the many factors that determine housing recovery. Until more quantitative studies capture the many layers of interdependencies, several pieces of this model will remain purely conceptual. Uncovering and measuring the complex layers and interdependencies is a long-term goal of the authors.

Table 1. Existing Public Data Sources for Quantifying Housing Recovery Variables

Public Data Source	**Housing Recovery Variable**
Local pre-disaster recovery plans	Building permits issuance
Local comprehensive land use plans	Change in land-use in previous neighborhood; number of connecting roads
Local hazard mitigation plans	Mandatory building retrofits
Local transportation plans	Number of connecting roads
Local planning or building department	Building damage repair rate; number, type and costs of permits; labor supply
Local utility companies	Electric power, clean water, and wastewater service availability; labor supply
Longitudinal tax assessment databases covering pre and post disaster	Occupancy status (vacant, occupied); building damage; building damage repair rate; percentage of undamaged vacancies
Census, or American Community Survey	Financial resource supply rate; median household income; age, gender, education distributions;
Small area population estimates (can be done by local planners or any demographer)	Population return
Google Maps and Google Earth	Presence of obstructing debris and hazard-specific obstruction; reconstruction progress
Army Corp of Engineers post-disaster surveys	Presence of obstructing debris and hazard-specific obstruction
FEMA's post-disaster damage assessment surveys	Building damage repair rate; percentage of damaged housing units; percentage of undamaged vacancies
Federal recovery assistance program: CDBG-DR regulations	Type of damage that can be covered by assistance programs; eligibility criteria for recovery assistance; financial assistance; grant allocations for repair/reconstruction
FEMA Minimum Home Repair grant program	Type of damage that can be covered by assistance programs; financial assistance; grant allocations for repair/reconstruction
FEMA Shelter at Home grant program	Type of damage that can be covered by assistance programs; financial assistance; grant allocations for repair/reconstruction
Small Business Administration	Type of damage that can be covered by assistance programs; financial assistance; loan approvals for repair/reconstruction
FEMA and NOAA inundation maps	Flood level
National Flood Insurance Program	Insured damage property data; financial resource supply rate; insurance money distributed

Closing Remarks

The model presented here addresses a critical gap in the disaster literature by investigating the interdependencies in the housing recovery process. Few studies have attempted to model recovery, particularly the long-term housing recovery process as a dynamic system from a holistic perspective. The proposed model integrated engineering and social science perspectives on post-disaster housing recovery. The primary purpose of the model was to provide a system which supported a better and deeper understanding of the housing recovery process, and to provide a platform for investigating policies and mitigation that can improve overall housing recovery and reduce recovery disparities across neighborhoods and housing units.

Our housing recovery model has three distinctive features that mark an attempt to improve upon previous recovery models: scalability, extendibility, and incorporation of policies. Housing recovery is a multi-disciplinary problem spanning multiple areas including structural engineering, construction management, urban planning, sociology, economics, and public policy, where one of the highest emphases is public policy. Before a disaster, communities have varying numbers and types of housing policies in place. After a disaster they often enact additional and different policies at different points throughout recovery. In the past, many of these post-disaster housing recovery policies have overlooked the socially vulnerable populations (Green & Olshansky, 2012; Nelson et al., 2007; Olshansky & Johnson, 2010). While this issue has been discussed by a number of qualitative studies and partially addressed in Hwang et al.'s (2014) model at the community level, there is still a critical need for investigating the role of assistance and construction policies on the timing and quality of housing recovery for different households. The model we introduced intends to take into account the role of housing recovery policies with respect to both aggregate housing recovery as well as differential housing recovery for socially vulnerable populations.

Our housing recovery model is applicable at the community, neighborhood and single housing unit-scale. As is, it can be used by communities, or other researchers, to conceptually investigate policies that improve the model outcomes, as well as mitigation programs that increase the initial structural integrity of the residential building stock. The model specifically addresses long-term housing recovery. Long-term housing recovery is influenced by the pre- and post-disaster recovery planning, the emergency response, temporary shelter program, and the short-term and temporary housing programs enacted. A portion of these different stages of housing recovery were captured in the presented model, however the connection with pre-disaster planning and short-term recovery can be incorporated through the delay time, policies, and the addition of new, specific elements. There is a great need in the resilience and recovery research communities to conduct more interdisciplinary research. In addition to the model itself, the present work contributes an example of how measures from multiple disciplines can be integrated into a single body of work.

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References

Albin, S. (1997). “Building a system dynamics model Part I: Conceptualization.” Copyright 1997 by the Massachusetts Institute of Technology.

Alesch, D. J., Arendt, L. A., & Holly, J. N. (2009). Managing for Long-term Community Recovery in the Aftermath of Disaster. Fairfax: VA Public Entity Risk Institute.

Arlikatti, S. & Andrew, S. (2012). “Housing design and long-term recovery processes in the aftermath of the 2004 Indian Ocean tsunami.” *Natural Hazards Review*, 13(1), 34-44.

Arlikatti, S., Peacock, W., Prater, C., Grover, H., & Gnana Sekar, A. (2010). “Assessing the impact of the Indian Ocean tsunami on households: a modified domestic assets index approach.” *Disasters*, 34(3), 705-731.

Berke, P.R., Lyles, W., & Smith, G. (2014). “Impacts of federal and state hazard mitigation policies on local land use policy. “ *Journal of Planning Education and Research*. doi: 0739456X13517004.

Bevington, J., Hill, A., Davidson, R., Chang, S., Vicini, A., Adams, B., & Eguchi, R. (2011). *Measuring, monitoring and evaluating post-disaster recovery: a key element in understanding community resilience*. Paper presented at Structures Congress, Las Vegas, Nevada.

Boano, C. (2009). “Housing anxiety and multiple geographies in post-tsunami Sri Lanka.” *Journal Compilation, Overseas Development Institute*, doi: 10.1111/j.0161-3666.2009.01108.x.

Bolin, R. (1982). “Long-tern family recovery from disaster.” Monograph #36. Boulder: University of Colorado, Institute of Behavioral Science.

Bolin, R. & Bolton, P. (1986). “Race, religion, and ethnicity in disaster recovery.” *FMHI Publications*, Paper 88.

Brown, D., Saito, K., Liu, M., Spence, R., So, E., & Ramage, M. (2012). “The use of remotely sensed data and ground survey tools to assess damage and monitor early recovery following the 12.5.2008 Wenchuan earthquake in China.” *Bull Earthquake Engineering*, 10, 741-764.

Burrus, R. T., Dumas, C. F. & Graham, J. E. (2011). "Hurricane Risk and Coastal Property Owner Choices." *International Journal of Disaster Resilience in the Built Environment* 2(2), 118-38. doi: 10.1108/17595901111149123.

Carter, N. T. (2014). "Federal Involvement in Flood Response and Flood Infrastructure Repair: Hurricane Sandy Recovery." Pp. 123-37 in *Adaptation Costs of Rising Sea Levels and Storm Flooding: An Economic Framework for Coastal Communities*: Nova Science Publishers, Inc.

Chang, S. E. (2010). "Urban Disaster Recovery: A Measurement Framework and Its Application to the 1995 Kobe Earthquake." *Disasters*, 34(2), 303-27. doi: 10.1111/j.1467-7717.2009.01130.x.

Chang, Y., Wilkinson, S., Potangaroa, R., & Seville, E. (2010). “Resourcing challenges for post-disaster housing reconstruction: a comparative analysis.” *Building Research and Information*, 38(3), 247-264.

Cheng, S., Ganapati, E., & Ganapati, S. (2015). “Measuring disaster recovery: bouncing back the counterfactual state?” *Disasters,* 39(3), 427-446.

City and County of San Francisco, California (2016). "Resilient San Francisco: Stronger Today, Stronger Tomorrow.”

Comerio, M. (2017). This is a chapter. In A. Sapat and A.M. Esnard (Eds.), *Coming Home after Disaster: Multiple Dimensions of Housing Recovery: Disaster Recovery and Community Renewal: Housing Approaches.* (pp. 3-20). Boca Raton, TL: Routledge.

Comerio, M. (2006). “Estimating Downtime in Loss Modeling.” *Earthquake Spectra*, 22(2), 349-365.

Comerio, M. (1997). “Housing Issues After Disasters.” *Journal of Contingencies and Crisis Management*, 5(3), 166-179.

Cui, Y., Daan, L., & Ewing, B. (2015). “Empirical Analysis of Building Permits in Response to Hurricane Landfalls.” *Natural Hazards Review*, 16(4), 04015009.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). “Social vulnerability to environmental hazards.” *Social Science Quarterly*, 84(2), 242–261.

Cutter, S. L., Schumann, R. L., & Emrich, C. T. (2014). Exposure, Social Vulnerability and Recovery Disparities in New Jersey after Hurricane Sandy. Journal of Extreme Events, 01(01), 1450002. doi: 10.1142/S234573761450002X.

Dash, N., Morrow, B., Mainster, J., & Cunningham, L. (2007). “Lasting effects of Hurricane Andrew on a working-class community.” *Natural Hazards Review*, 8(1), 13-21.

Diaz, R., Kumar, S., & Behr, J. (2015). “Housing recovery in the aftermath of a catastrophe: Materials resources perspective.” *Computers and Industrial Engineering*, 81, 130-139.

EIA (2013). “How much energy is consumed in residential and commercial buildings in the United States?” Independent Statistics and Analysis. U.S. Energy Information Administration. www.eia.gov.

El-Anwar, O. (2010). *Optimizing alternative housing projects in the aftermath of natural disasters*. Paper presented at the meeting of Construction Research Congress, Alberta, Canada.

El-Anwar, O., El-Rayes, K. & Elnashai, A. (2008). “Multi-Objective Optimization of Temporary Housing for the 1994 Northridge Earthquake”. *Journal of Earthquake Engineering*, 12(S2), 81–91.

El-Anwar, O., El-Rayes, K., & Elnashai, A. (2010a). “Maximizing the sustainability of integrated housing recovery efforts.” *Journal of Construction Engineering and Management*, 136(7), 794-802.

El-Anwar, O., El-Rayes, K., & Elnashai, A. (2010b). “Minimization of socioeconomic disruption for displaced population following disasters.” *Disasters*, 34(3), 865–883.

El-Anwar, O. (2013). “Advancing optimization of hybrid housing development plans following disasters: achieving computational robustness, effectiveness, and efficiency.” *Journal of Computing in Civil Engineering*, 27(4), 358-369.

Elliott, J., Hite, A., & Devine, J. (2009). “Unequal return: the uneven resettlements of New Orleans’ uptown neighborhoods.” *Organization and Environment*, 22(4), 410-421.

Erikson, K. (1976). *Everything in Its Path: Destruction of Community in the Buffalo Creek Flood*. Simon and Schuster, New York.

Fothergill, A., and Peek, L. (2015). “Children of Katrina.” University of Texas Press. Austin, Texas.

Fothergill, A. (1999). “An exploratory study of woman battering in the Grand Forks Flood disaster: Implications for community responses and policies.” *International Journal of Mass Emergencies and Disasters*, 17(1), 79–98.

Francisco, J. P. (2015). "Determinants of Property Damage Recovery Time Amongst Households Affected by an Extreme Flood Event in Metro Manila, Philippines." *Jamba: Journal of Disaster Risk Studies,* 6(1). doi: 10.4102/jamba.v6i1.119.

Godschalk, D.R., Brower, D.J., & Beatley, T. (1989). *Catastrophic coastal storms: Hazard mitigation and development management*. Durham: Duke University Press.

Golec, J. (1983). “A contextual approach to the social psychology study of disaster recovery.” *International Journal of Mass Emergencies and Disasters*¸ 255-277.

Green, T. F. & Olshansky, R. (2012). "Rebuilding Housing in New Orleans: The Road Home Program after the Hurricane Katrina Disaster." *Housing Policy Debate,* 22(1), 75-99. doi: 10.1080/10511482.2011.624530.

Green, R., Bates, L., & Smyth, A. (2007). “Impediments to recovery in New Orleans’ upper and lower Ninth Ward: one year after Hurricane Katrina.” *Disasters,* 31(4), 311-335.

Haimes, Y., Horowitz, B., Lambert, J., Santos, J., Lian, C., & Crowther, K. (2005). “Inoperability Input-Output Model for Interdependent Infrastructure Sectors. I: Theory and Methodology.” *Journal of Infrastructure Systems*, 11(2), 67-79.

Hamideh, S. & Sutley, E.J. (2017). “Housing Recovery: A Systematic Review.” *In Preparation*.

Hamideh, S., Peacock, W.G., & Van Zandt, S. (2017). “Recovery Disparities among Housing Types.” *In Preparation.*

Hayashi, H. (2007). Long-term Recovery from Recent Disasters in Japan and the United States. Journal of Disaster Research, 2(6), 413-418.

He, X. & Cha, E. (2017). “Modeling the damage and recovery of interdependent critical infrastructure systems from natural hazards.” In Review.

Henneberger, J. (2010). “Current FEMA Disaster recovery policy will leave low-income hurricane survivors unassisted.” Texas Housers, Texas Low Income Housing Information Service. <texashousers.net/2010/07/01/>.

Highfield, W., Peacock, W., & Van Zandt, S. (2014). "Mitigation Planning: Why Hazard Exposure, Structural Vulnerability, and Social Vulnerability Matter." *Journal of Planning Education and Research*. doi: 10.1177/0739456x14531828.

Hill, A., Bevington, J., Davidson, R., Chang, S., Eguchi, R., Adams, B., Brink, S., … (2011). “Community-scale damage, disruption, and early recovery in the 2010 Haiti earthquake.” *Earthquake Spectra*, 27(S1), S431-S446.

Hirayama, Y. (2000) “Collapse and reconstruction: housing recovery policy in Kobe after the Hanshin great earthquake”. *Housing Studies*, 15 (11), 111–28.

Hoshi, T., Murao, O., Yoshino, K., Yamazaki, F., & Estrada, M. (2014). “Post-disaster urban recovery monitoring in Pisco after the 2007 Peru earthquake using satellite image.” *Journal of Disaster Research*, 9(6), 1059-1069.

Hwang, D. (2011). *Disaster recovery planning: lessons learned from past events*. Paper presented at *Solutions to Coastal Disasters*, Anchorage, Alaska.

Hwang, S., Park, M., Lee, H.S., Lee, S., & Kim, H. (2014). “Postdisaster interdependent built environment recovery efforts and the effects of governmental plans: case analysis using system dynamics.” *Journal of Construction Engineering and Management*, 141(3), 04014081.

Ireton, G., Ahmed, I., & Charlesworth, E. (2014). “Reflections on residential rebuilding after the Victorian Black Saturday bushfires.” *Open House International*, 39(3), 70-78.

Johnson, L. A., & Hayashi, H. (2012). Synthesis Efforts in Disaster Recovery Research. International Journal of Mass Emergencies and Disasters, 30(2), 212-238.

Kamel, N. (2012). “The actualization of neoliberal space and the loss of housing affordability in Santa Monica, California.” *Geoforum*, 43, 453-463.

Khazai, B. & Hausler, E. (2005). “Intermediate shelters in Bam and permanent shelter reconstruction in villages following the 2003 Bam, Iran earthquake.” *Earthquake Spectra*, 21(S1).

Kikitsu, H. & Sarkar, P. (2014). “Building damage, wind speed estimation, and post disaster recovery in an EF5 tornado.” *Natural Hazards Review*, 16(2), 04014019.

Kumar, S., Diaz, R., Behr, J., & Toba, A. (2015). “Modeling the effects of labor on housing reconstruction: A system perspective.” *International Journal of Disaster Risk Reduction*, 12, 154-162.

Landenback, R. & Dusi, A. (2004). “On the cross of Sant’Andrea: the response to the tragedy of San Giuliano di Puglia following the 2002 Molise, Italy, Earthquake.” *Earthquake Spectra*, 20(S1), S341-S358.

Lester, H., Perry, M., & Moynihan, G. (2014). *Detecting shift moments in construction activity to estimate disaster recovery*. Paper presented at the Second International Conference on Vulnerability and Risk Analysis and Management (ICVRAM) and the Sixth International Symposium on Uncertainty, Modeling, and Analysis (ISUMA), Liverpool, UK.

Levine, J., Esnard, A.M., & Sapat, A. (2007). “Population displacement and housing dilemmas due to catastrophic disasters.” *Journal of American Planning Literature*, 22(1). doi: 10.1177/0885412207302277.

Liel, A., Corotis, R., Camata, G., Sutton, J., Holtzman, R., & Spacone, E. (2013). "Perceptions of decision-making roles and priorities that affect rebuilding after disaster: the example of L'Aquila, Italy." *Earthquake Spectra*, 29(3), 843-868.

Lindell, M., Brody, S., & Highfield, W. (2017). This is a chapter. In A. Sapat and A.M. Esnard (Eds.), *Coming Home after Disaster: Multiple Dimensions of Housing Recovery: Financing Housing Recovery through Hazard Insurance: The Case of the National Flood Insurance Program.* (pp. 49-65). Boca Raton, TL: Routledge.

Lizarralde, G., Johnson, C., & Davidson, C. (2003). Houses of candied sugar: comparative research on controversial temporary housing after earthquake disasters in Colombia and Turkey. Proceedings, International Association for Housing Science World Congress on Housing Process and Product

Lowe, J. (2012). "Policy versus politics: post-Hurricane Katrina lower-income housing restoration in Mississippi." *Housing Policy Debate*, 22(1), 57-73.

Lu, Y. & Xu, J. (2014). "Comparative study on the key issues of post-earthquake recovery and reconstruction planning: lessons from the United States, Japan, Iran, and China." *Natural Hazards Review*, 16(3), 04014033.

Lui, A. & Plyer, A. (2008), *The New Orleans Index, Tracking Recovery of the New Orleans Metro Area: Anniversary Edition Three Years After Katrina*. The Brookings Institute and Greater New Orleans Community Data Center. August.

Masozera, M., Bailey, M., & Kerchner, C. (2007). "Distribution of impacts of natural disaters across income groups: A case study of New Orleans." *Ecological Economics*, 63, 299-306.

McAneney, J., McAneney, D., Musulin, R., Walker, G. & Crompton, R. (2016). "Government-Sponsored Natural Disaster Insurance Pools: A View from Down-Under." *International Journal of Disaster Risk Reduction*, 15, 1-9. doi: 10.1016/j.ijdrr.2015.11.004.

Merdjanoff, A. (2015). "Weathering the storm: the long-term effects of Hurricane Katrina on mental health, mobility, and recovery." A Dissertation. Rutgers University.

Mitchell, C., Esnard, A., & Sapat, A. (2012). "Hurricane events, population displacement, and sheltering provision in the United States." *Natural Hazards Review*, 13(2), 150-161.

Mitrani-Reiser, J. (2007). "An ounce of prevention: Probabilistic loss estimation for performance-based earthquake engineering." Ph.D. thesis, California Institute of Technology, Pasadena, CA.

Mukherji, A. (2010). "Post-earthquake housing recovery in Bachhau, India: The homeowner, the renter and the squatter." *Earthquake Spectra*, 26(4), 1085-1100.

Muskal, M. (2012). "Last FEMA trailer leaves New Orleans six years after Katrina." Los Angeles Times, February 15, 2012. http://latimesblogs.latimes.com/nationnow/2012/02/last-fema-trailer-leaves-new-orleans-six-years-after-hurricane-katrina.html.

NCDP (2015). "Person Report The Sandy Child and Family Health Study." Briefing Report No. 2. National Center for Disaster Preparedness.

Nejat, A. & Damnjanovic, I. (2012). “Agent-based modeling of behavioral housing recovery following disasters.” *Computer-Aided Civil and Infrastructure Engineering*, 27, 748-763.

Nejat, A. & Ghosh, S. (2016). “LASSO model of postdisaster housing recovery: case study of Hurricane Sandy.” *Natural Hazards Review*, 17(3), 04016007.

Nelson, M., Ehrenfeucht, R. & Laska, S. (2007). "Planning, Plans, and People: Professional Expertise, Local Knowledge, and Governmental Action in Post-Hurricane Katrina New Orleans." *Cityscape*, 9(3), 23-52. doi: 10.2307/20868630.

Nguyen, M. & Salvesen, D. (2014). “Disaster recovery among multiethnic immigrants.” *Journal of the American Planning Association*, 80(4), 385-398.

Olshansky, R. B., Hopkins, L. D., & Johnson, L. A. (2012). Disaster and Recovery: Processes Compressed in Time. Natural Hazards Review, 13(3), 173-178. doi:10.1061/(ASCE)NH.1527-6996.0000077.

Olshansky, R. & Johnson, L. (2010). *Clear as Mud: Planning for the Rebuilding of New Orleans*. Washington, DC: APA Planners Press.

Olshansky, R., Nakabayashi, I., & Ohnishi, K. (2006). Socioeconomic, policy, and planning aspects of the 2004 Niigata Ken Chuetsu Earthquake.” *Earthquake Spectra*, 22(S1), S163-S175.

Paul, B., & Che, D. (2011). “Opportunities and challenges in rebuilding tornado-impacted Greensburg, Kansas as “stronger, better, and greener”.” *GeoJournal*, 76, 93-108.

Peacock, W., Van Zandt, S., Zhang, Y. & Highfield, W. (2014). "Inequities in Long-Term Housing Recovery after Disasters." *Journal of the American Planning Association*, 80(4), 356-71.

Peacock, W. G., Dash, N., & Zhang, Y. (2007). This is a chapter. In H. Rodriguez, E. L. Quarantelli, & R. Dynes (Eds.), *The handbook of disaster research: Sheltering and housing recovery following disaster*. (pp. 258–274). New York, NY: Springer.

Phillips, B., & Seeley, S. (2017). This is a chapter. In A. Sapat and A.M. Esnard (Eds.), *Coming Home after Disaster: Multiple Dimensions of Housing Recovery: Tornado Housing Recovery*. (pp. 113-126). Boca Raton, TL: Routledge.

Quarantelli, E. (1982). “What is disaster? The need for clarification in definition and conceptualization in research.” *Disasters and Mental Health Selected Contemporary Perspectives*, 41-73.

Rathfon, D., Davidson, R., Bevington, J., Vicini, A., & Hill, A. (2013). "Quantitative Assessment of Post-Disaster Housing Recovery: A Case Study of Punta Gorda, Florida, after Hurricane Charley." *Disasters*, 37(2), 333-55. doi: 10.1111/j.1467-7717.2012.01305.x.

Rakes, T., Deane, J., Rees, L., & Fetter, G. (2014). “A decision support system for post-disaster interim housing.” *Decision Support Systems*, 68, 160-169.

Rinaldi, S., Peerenboom, J., & Kelly, T. (2001). “Identifying, understanding, and analyzing critical infrastructures interdependencies.” *IEEE Control Systems Magazine*, December 2001, 0272-1078/01.

Ritchie, L., & Tierney, K. (2011). “Temporary housing planning and early implementation in the 12 January 2010 Haiti earthquake.” *Earthquake Spectra*, 27(S1), S487-S507.

Reitherman, R., & Cobeen, K. (2003). “Design documentation of woodframe project index buildings.” Consortium of Universities for Research in Earthquake Engineering, Richmond, CA.

Rossetto, T., D’Ayala, D., Fori, F., Persio, R., Han, J., Novelli, V., Wilkinson, S., …, (2014). “The value of multiple earthquake missions: the EEFIT L’Aquila Earthquake experience.” *Bull Earthquake Engineering*, 12, 277-305.

Sapat, A. (2017). This is a chapter. In A. Sapat and A.M. Esnard (Eds.), *Coming Home after Disaster: Multiple Dimensions of Housing Recovery: Politics of Disaster Recovery: Policy and Governance Challenges in Post-Disaster Housing.* (pp. 67-79). Boca Raton, TL: Routledge.

Sapat, A. & Esnard, A.M. (2017). *Coming Home after Disaster: Multiple Dimensions of Housing Recovery.* Boca Raton, TL: Routledge.

Siembieda, W., Johnson, L., & Franco, G. (2012). “Rebuild fast but rebuild better: Chile’s initial recovery following the 27 February 2010 earthquake and tsunami.” *Earthquake Spectra*, 29(S1), S621-641.

Simon, A., Arlikatti, S., Long, L., & Kendra, J. (2013). “The effect of housing assistance arrangements on household recovery: an empirical test of donor-assisted and owner-driven approaches.” *Journal of Housing and the Built Environment*, 28, 17-34.

Smith, G. (2012). *Planning for post-disaster recovery: A review of the United States disaster assistance framework*. Washington DC: Island Press.

Smith, G. & Wenger, D. (2007). “Sustainable disaster recovery: operationalizing an existing agenda.” *Handbook of disaster research* (pp. 234-257). New York: Springer.

Spader, J. & Turnham, J. (2014). “CDBG Disaster Recovery Assistance and Homeowners’ Rebuilding Outcomes Following Hurricanes Katrina and Rita.” *Housing Policy Debate*, 24(1), 213-237.

Stevenson, J., Emrich, C., Mitchell, J., & Cutter, S. (2010). “Using building permits to monitor disaster recovery: A spatio-temporal case study of coastal Mississippi following Hurricane Katrina.” *Cartography and Geographic Information Science*, 37(1), 57-68.

Sutley, E.J., van de Lindt, J.W., & Peek, L. (2016a). “Community-Level Framework for Seismic Resilience, Part I: Coupling Socioeconomic Characteristics and Engineering Building Systems.” *Natural Hazards Review*, 04016014.

Sutley, E.J., van de Lindt, J.W., & Peek, L. (2016b). “Community-Level Framework for Seismic Resilience, Part II: Multi-Objective Optimization and Illustrative Examples.” *Natural Hazards Review*, 04016015.

Sutley, E.J., & van de Lindt, J.W. (2016). “Evolution of Predicted Seismic Performance for Wood-Frame Buildings.” Journal of Architectural Engineering, DOI: 10.1061/(ASCE)AE.1943-5568.0000212, B4016004.

Tafti, M. & Tomlinson, R. (2014). “Best practice post-disaster housing and livelihood recovery interventions: winners and losers.” *International Development Planning Review*, 37(2), doi: 10.3828/idpr.2015.14

Van Zandt, S., & Sloan, M. (2017). This is a chapter. In A. Sapat and A.M. Esnard (Eds.), *Coming Home after Disaster: Multiple Dimensions of Housing Recovery: The Texas Experience with 2008’s Hurricanes Dolly and Ike*. (pp. 83-97). Boca Raton, TL: Routledge.

Van Zandt, S., Peacock, W., Henry, D., Grover, H., Highfield, W. & Brody, S. (2012). "Mapping Social Vulnerability to Enhance Housing and Neighborhood Resilience." *Housing Policy Debate*, 22(1), 29-55. doi: 10.1080/10511482.2011.624528.

Wachtendorf, T., Kendra, J., Rodriguez, H., & Trainor, J. (2006). “The social impacts and consequences of the December 2004 Indian Ocean Tsunami: observations from India and Sri Lanka.” *Earthquake Spectra*, 22(S3), S693-S714.

Weber, J., & Lichtenstein, B. (2015). "Building back: stratified recovery after an EF-4 tornado in Tuscaloosa, Alabama." *City and Community*, 14(2), 186-206.

Wright, J. D., Rossi, P. H., Wright, S. R., & Weber-Burdin, E. (1979). After the clean-up: Long-range effects of natural disasters, Sage, Beverly Hills, Calif.

Wu, J. & Lindell, M. (2004). "Housing reconstruction after two major earthquakes: the 1994 Northridge Earthquake in the United States and the 1999 Chi-Chi Earthquake in Taiwan." *Disasters*, 28(1), 63-81.

Xiao, Y., & Van Zandt, S. (2012). "Building community resiliency: Spatial links between household and business post-disaster return." *Urban Studies*, 49(1), 2523-2542.

Zhang, Y. (2012). "Will natural disasters accelerate neighborhood decline? A discrete-time hazard analysis of residential property vacancy and abandonment before and after Hurricane Andrew in Miami-Dade County (1991-2000)." *Environment and Planning B: Planning and Design*, 39, 1084-1104.

Zhang, Y. & Peacock, W. (2010). "Planning for Housing Recovery? Lessons Learned from Hurricane Andrew." *Journal of the American Planning Association*, 76(1), 5-24. doi: 10.1080/01944360903294556.

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[1] Rubin, 1985; Olshansky, Hopkins, & Johnson 2012; Sapat & Esnard, 2017

[2] For an extensive and in-depth review of the literature on housing recovery, the interested reader is referred to Hamideh and Sutley (2017).

[3] This statement is based on a recent field study conducted by the authors.

[4] Ireton, Ahmed, and Charlesworth, 2014; Siembieda, Johnson, & Franco, 2012; Rathfon et al., 2013; Mitchell, Esnard, & Sapat, 2012

[5] Hwang, 2011; Stevenson, Emrich, Mitchell, & Cutter, 2013; Green et al., 2013; Green, 2012; Kamel, 2012; Peacock et al., 2014; Rathfon et al., 2013; Spader & Turnham, 2014; Weber & Lichtenstein, 2015; Green et al., 2007

[6] Brown et al., 2012; Khazai & Hausler, 2005; Liel et al., 2013; Rossetto et al., 2014; Paul & Che, 2011; Hwang, 2011

[7] Bevington et al., 2011; Brown et al., 2012; Hill et al., 2011; Hoshi, Murao, Yoshino, Yamazaki, & Estrada, 2014; Kikitsu & Sarkar, 2014; Green et al., 2007; Hirayama, 2000; Kamel, 2012; Kumar et al., 2015; Rathfon et al., 2013; Spader & Turnham, 2014; Tafti & Tomlinson, 2014; Khazai & Hausler, 2005; Liel et al., 2013; Rossetto et al., 2014; Siembieda et al., 2012

[8] Stevenson et al., 2013; Green et al., 2007; Cheng et al., 2015; Weber & Lichtenstein, 2015; Lester, Perry, & Moynihan, 2014

[9] Lui & Plyer, 2008; Chang 2010; Lu & Xu, 2014

[10] Lu & Xu, 2014; Chang, 2010; Elliott, Hite, & Devine, 2009

[11] Green, 2012; Mukherji, 2010; Masozera, Bailey, Kerchner, 2007; Spader & Turnham, 2014

[12] Chang, Wilkinson, Potangaroa, & Seville, 2010; Hwang, 2011