Quantifying the Importance of Social Infrastructure in Community Resilience using Social Capital

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Abstract:

Social capital is the networks of relationships between people of a specific area that provide them with access to resources and power. Social capital has been shown to have numerous benefits in a community during times of typical functioning through developing and providing a sense of community to the population, and post-disaster through people utilizing that sense of community through providing aid and resources to other community members. Social capital is often grown, and its benefits are often facilitated, through social infrastructure. Examples of social infrastructure include churches, libraries, museums, parks, and many more, all of which are often used to build networks and relationships, and to connect people. Social capital is a critical piece of what makes a community resilient to disasters. However, social capital is typically omitted from quantitative realizations of community resilience.

This study provides a method of quantifying social capital as it is provided by social infrastructure and affiliated social organizations through the development of three indices which measure the importance of (1) the organization (Organization Social Capital Index), (2) the physical structure housing the organization (Building Social Capital Index), and (3) the interdependencies between the social organization with critical facilities (Critical Infrastructure Interdependency Index). Calculation and analysis of the three indices allow for prioritization of social infrastructure within a community, whether in typical functioning or the post-disaster setting. Equations are developed initially, then adapted to fit three different phases of a hazard scenario, namely the pre-disaster conditions, the hazard event, and long-term community recovery. The indices are further exemplified to provide a method of measuring social capital facilitated through any type of community building (e.g. restaurant, police station, house).

Prioritizing social infrastructure can be examined through post-disaster resource allocation, or through pre-disaster mitigation. The latter is exemplified here through the performance-based
seismic design of a two-story church building archetype. The archetype was designed using cross-laminated timber (CLT) panels as the lateral force resisting system following the Simplified Direct Displacement Design methodology and setting immediate occupancy as the performance objective for a maximum considered earthquake (MCE) in San Francisco, California. This thesis demonstrates that designing social infrastructure to higher levels can preserve on average 45% of social capital generated by the organization and 60% of the building’s social capital during an MCE hazard scenario. These findings should be considered by decision makers at the local level, and national level for improved prioritization of recovery resource allocation, and in the consideration of redefining the risk categories for social infrastructure buildings.
# Table of Contents

Chapter 1: Introduction ............................................................................................................... 1
Chapter 2: Literature Review .................................................................................................... 9
  2.1 Resilience Frameworks ................................................................................................. 9
    2.1.1 Establishing the Definition of Resilience .............................................................. 9
    2.1.2 Vulnerability-Based Resilience Frameworks ......................................................... 12
    2.1.3 Components of a Resilient System ....................................................................... 15
    2.1.4 Practical Resilience Frameworks ......................................................................... 20
  2.2 Social Capital ................................................................................................................. 24
    2.2.1 Social Capital Definition ..................................................................................... 25
    2.2.2 Social Capital and the Built Environment ............................................................ 27
    2.2.3 Benefits of Social Capital .................................................................................... 29
    2.2.4 Linking Social Capital Case Studies .................................................................... 31
    2.2.5 Bridging Social Capital Case Studies .................................................................. 33
    2.2.6 Social Capital from Organizations ..................................................................... 35
Chapter 3: Social Capital Model ............................................................................................. 40
  3.1 Organization Social Capital Index ................................................................................. 44
  3.2 Formulation of Organization Social Capital Index ....................................................... 55
  3.3 Building Social Capital Index ...................................................................................... 56
  3.4 Formulation of Building Social Capital Index ............................................................. 65
  3.5 Critical Infrastructure Interdependency Index ............................................................. 66
  3.6 Variations in Index Measures Under Different Hazard Scenarios ............................... 69
Chapter 4: Cross-Laminated Timber (CLT) Design ............................................................... 74
  4.1 CLT Literature Review ................................................................................................. 74
  4.2 Performance-Based Seismic Design ............................................................................ 81
  4.3 Design Process & Methods ........................................................................................ 83
  4.4 Building Seismic Performance ................................................................................... 91
Chapter 5: Social Capital Index Examples .......................................................................... 100
  5.1 Semi-Structured Interviews for Data Collection ....................................................... 100
  5.2 Interview Results ..................................................................................................... 101
  5.3 Monte Carlo Simulation Investigation of Critical Variables in Indices ...................... 109
  5.4 Comparing Social Capital across Hazard Scenarios ................................................. 114
  5.5 Comparing Social Capital of Typical Community Buildings to Social Infrastructure 120
Chapter 6: Conclusions and Recommendations .................................................................. 132
Chapter 7: References .......................................................................................................... 137
List of Figures

Figure 1: Resilience Triangle from Francis and Bekera (2014) ................................................................. 15
Figure 2: Resilience Framework Including Social Capital ................................................................. 41
Figure 3: Social Capital Index Research Framework ........................................................................... 43
Figure 4: CLT panel configuration from Karacabeyli and Douglas (2013) ............................................ 75
Figure 5: Ten-parameter hysteretic model from Pei et al. (2013) ....................................................... 77
Figure 6: Two-story church building first floor layout and dimensions .............................................. 84
Figure 7: Two-story church building second floor layout and dimensions ........................................... 85
Figure 8: CLT wall panel bracket layout from Karacabeyli and Douglas (2013) .................................. 88
Figure 9: CLT wall panel load tables developed by Karacabeyli and Douglas (2013) ..................... 88
Figure 10: CLT panel layout for first floor ............................................................................................ 90
Figure 11: Overlay of tests #18 and #10 from Amini et al. (2016) with sketched lines ................... 93
Figure 12: Results of comparison from Amini et al. (2016) tests ....................................................... 95
Figure 13: Probability of exceedance curves for CLT building .......................................................... 98
Figure 14: Probability of exceedance curves for CLT and ALL test structures ................................ 99
Figure 15: Social organization reference interview answers ............................................................. 102
Figure 16: Organization Social Capital Index results from reference interviews ............................. 104
Figure 17: Building Social Capital Index results from reference interviews ..................................... 106
Figure 18: Total social capital results from reference interviews .................................................... 109
Figure 19: Monte Carlo simulation of OSCI with lognormal distribution for membership number .... 110
Figure 20: Monte Carlo simulation of BSCI with lognormal distribution for building age ............... 112
Figure 21: Monte Carlo simulation of BSCI using building age and emergency shelter variables ...... 113
Figure 22: Organization Social Capital Index under different hazard phases .................................. 115
Figure 23: OSCI percent drop between pre-disaster conditions and recovery phase ....................... 116
Figure 24: Building Social Capital Index under different hazard phases ........................................ 117
Figure 25: Difference in recovery-phase social capital for improved building performance ............ 118
Figure 26: Organization (left) and Building (right) social capital index values at the no hazard phase... 123
Figure 27: OSCI for social organizations and typical community buildings under hazard scenario ...... 125
Figure 28: BSCI for social organizations and typical community buildings under hazard scenario .... 126
Figure 29: Total Social Capital for all community buildings ............................................................. 131
Figure 30: Impact of social capital on community functionality ....................................................... 135

List of Tables

Table 1: Resilience Definitions ........................................................................................................... 10
Table 2: Organization Social Capital Index (OSCI) variable definitions ......................................... 56
Table 3: Building Social Capital Index (BSCI) variable definitions .................................................. 66
Table 4: Critical Infrastructure Interdependency Index values for social organizations ............... 107
Table 5: Critical Infrastructure Interdependency Index values for other community buildings ....... 129
Chapter 1: Introduction

The goal of this thesis is to provide a way for researchers and decision makers to quantify social capital developed and/or facilitated through social infrastructure and their associated social organizations. The approach to achieving this goal included the development of three new indices: organization social capital index; building social capital index; and critical infrastructure interdependency index. The index formulations were altered to capture the differences during three phases of a hazard scenario, namely pre-disaster, the hazard event, and long-term recovery. A hazard is defined here as a negative impact to a system; specifically, in this thesis the hazard is a natural hazard. The indices were formulated through a robust examination of the characteristics and features that social infrastructure and social organizations possess to facilitate social capital in a community. The social capital indices are exemplified on a range of building and organization types typically seen in a community, including those that are not classified as social infrastructure or social organizations to demonstrate the difference in social capital measurement. Providing a measure for social capital has three direct benefits: (1) it advocates for better design or prioritized recovery resource allocation to social infrastructures; (2) it provides a method to find the most socially impactful organization within a community; (3) it advances the current state of knowledge on what constitutes a resilient community.

Extensive research has been and is being conducted on infrastructure resilience. Infrastructure resilience is distinguished here from community resilience as being focused on an individual (physical) infrastructure, rather than considering the entire community. Infrastructure resilience research has mostly been focused on the advancement of performance-based building design to performance-based engineering. Performance-based design is a philosophy that articulates performance objectives through establishing performance goals at specific hazard
levels. In general, performance-based design is aimed at designing for extreme events, and therefore aims at designing structures to achieve performance beyond current code-levels to achieve better structural performance to minimize damage. Performance-based engineering is a philosophy that is applicable to more than buildings, and provides tradeoffs across multiple objectives for decision makers, building owners or other stakeholders to consider, including initial cost, hazard risk, structural and nonstructural performance, and financial loss if damaged. In the performance-based philosophies, the impetus is to minimize damage, i.e. to “keep standing”, post-disaster, but what does that look like for a community of people? Community resilience is more complex than either performance-based design or performance-based engineering; its multifaceted nature spans infrastructure, society, governance, and the environment. Community resilience aims to minimize disruption for the community, including its local government, its local organizations, its commerce, and its people.

The breadth of community resilience extends far beyond physical aspects and into interconnected social, economic, and technical mechanisms. The resilience of a community comes from various capitals or resources held within the community that provide the strength of that community to resist, bounce back, or transform, from a disruption. The National Institute of Standards and Technology (NIST) Community Resilience Guide (NIST 2015) defines seven types of capital. One of these is structural, referred to as built capital. The other types of capital in a community are financial, political (government capabilities), human (knowledge and abilities of members), cultural (language, attitudes, or orientations of members), natural (air, land, or water resources), and social, where measuring social capital is the primary motivation of this study. Greater amounts of each of these capitals positively contribute to how a community will bounce back after a disaster, and all seven capitals are interconnected in working for effective recovery.
As an example, a community with higher built capital, achieved through having all infrastructure designed to current standards or better, and high financial capital can still be significantly impacted from a hazard event if the local government and its organization is unable to mobilize the community’s resources rapidly and effectively (e.g. where the same community has low political and human capital).

As stated previously, social capital is the networks of relationships between people of a specific area that provide them with access to resources and power. High amounts of social capital represent a community that is well connected, and a place where residents desire to remain living. Social capital is important in the typical functioning of a community; having higher social capital has been attributed to having happier community members, positive mental health (Aldrich 2011a), and reduced crime rates (Tierney 2014). Studies have also shown that social capital will promote better recovery in a community after a disaster. For example, Nakagawa and Shaw (2004) found that in well-connected communities, members were quicker to offer aid and help people they knew after a large earthquake. Butterworth (2005) found that returning to regularly scheduled social events, which were Major League Baseball games in the study, helped provide comfort and a sense of normalcy to the American people after the 9/11 attacks. These are just two examples of the benefits of high social capital; many more are presented in Section 2.2.

Social capital can be built in a community through participation and actions such as voting or reading the newspaper (Nakagawa and Shaw 2004). While these actions can be important to a community and its members, they are performed on an individual-basis, rather than in groups, and therefore are not as strong as social capital promoting actions that engage multiple people at a time. A case study by Chamlee-Wright and Storr (2011) found that the inability to recreate their sense of community in another place was a motivating factor for people to remain in their neighborhood
or city after a disaster. Voter participation or reading the newspaper (as used by Nakagawa and Shaw 2004) are not social capital actions that typically develop a feeling of community or sense of place for an individual or family. Inclusion and participation in social organizations, however, can create that feeling.

Social organizations focus on building relationships and/or providing an attachment to the community (e.g. a sense of place). Examples of social organizations include religious organizations, non-profit or mission-based organizations, public recreation- and education-based organizations. These types of organizations are housed in a specific classification of physical infrastructure called social infrastructure, and include churches, museums, libraries, recreation centers, parks, and more. This research focuses on social organizations hosted through the built environment and therefore does not include social infrastructure such as parks that do not have a structurally-designed space. Social infrastructure exists in every community, and help define (and grow) the social capital of that community. Each community has different types of social organizations and infrastructure that most impactfully affect social capital. For example, a 1978 dam break caused immense flooding in Buffalo Creek, West Virginia. As the community began to rebuild, they chose to prioritize repair of their ice skating rink, as it was a staple of yearly winter celebrations (Erikson 1978). Regardless of the community or specific organization, social organizations make a community feel like home and build relationships that are not easily broken. Erikson (1978) reported that bringing back social engagement in Buffalo Creek through the ice skating rink helped the community recover faster compared to investing money in reconstruction, due to the sense of normalcy that the ice skating provided to the community members.

As mentioned above, and is further developed in the following chapters, social capital has immense importance to a community and its resilience. However, community resilience has
proved to be difficult to measure and quantify holistically. In infrastructure resilience, decisions can be made based on quantitative values, such as physical loads, structural member sizing, and engineering demand parameters to measure structural performance. Decision-makers want to effectively quantify their community’s resilience which requires quantifying the seven capitals discussed above.

Built capital and financial capital are largely the only two capitals with associated robust measurement science. This study develops a methodology for measuring social capital through applying a mixed methods approach to formulate three composite indices. The first index measures the importance of the organization and the interconnectedness of its members, and is referred to as the Organization Social Capital Index (OSCI). The second index, the Building Social Capital Index (BSCI), measures the impact that the building which houses the social organization has in terms of what it adds to social capital (Glanz 2011 and Carpenter 2013), as well as what the structure is able to provide post-disaster during response and recovery. A third index was developed to provide the appropriate context of the social organizations and corresponding infrastructure within the community. The most important buildings within a community are categorized as critical infrastructure, and include hospitals and power plants. Critical infrastructure is designed to a higher risk category considering that their continued functionality is vital to a community under the maximum considered hazard scenario. Critical infrastructure is not stand-alone; it requires additional types of infrastructure to continually function. Hence, the third index was formulated to account for the interdependencies that the building or organization under study has with critical infrastructure, and is called the Critical Infrastructure Interdependency Index (CIII).

The three social capital indices are intended to be adopted by government (or other) leaders and decision makers to determine the importance of buildings within their community considering
their influence on social capital. In a typical or pre-hazard community setting, this can lead to endorsing design for higher risk category assignment and subsequent building performance since these structures will have a significant impact on the community as long as they remain functional. In a hazard recovery setting, those decision makers could choose to prioritize the rebuilding of those social infrastructures that produce the highest amount of social capital in their community. To exemplify the significance of these actions, the indices are exemplified on various types of social organizations, social infrastructure, and other types of community buildings, such as homes, businesses, schools, factories, and more.

The current status of the community influences the amount of social capital being generated in a community. Additionally, the community’s status affects the manifestation of social capital, and how social capital is used by its people. In this research, the different community status is based on a natural hazard event, specifically investigated for a seismic event. The community status is articulated to possess three different values, or phases, including pre-disaster functioning, the hazard event, and the long-term recovery period occurring during the weeks to months following a disaster. Contributing factors to social capital differ on whether the community is functioning normally, whether a disaster has just occurred, or whether the community is in the midst of recovery. Hence, each of the three indices are exemplified during the three different phases along the disaster timeline.

The effects of the social infrastructure losing functionality is shown to have negative effects on social capital, as it leads to the social organization no longer having regular functions either. To combat this, the social capital indices can be used to establish a hierarchy, in addition to the existing critical infrastructure hierarchy, that accounts for the importance social infrastructure plays in community resilience and recovery. Adopting performance-based design, and designing
social infrastructures to higher performance objectives, such as continued or immediate occupancy, will allow the infrastructure (and therefore the organization) to remain functional. Functioning social infrastructures will continually grow social capital within the organization and the community, thereby promoting resilience and recovery. To exemplify this possibility, a series of examples demonstrate the three indices previously described during an earthquake disaster scenario. A search of existing literature revealed a lack of social infrastructure models available to researchers. Therefore, a two-story church building was designed following the Simplified Direct Displacement Design (SDDD) methodology (Pang et al. 2010), a performance-based design methodology. The lateral force resisting system utilized cross-laminated timber (CLT) panels to achieve the required higher seismic performance. Non-linear time history analysis was performed to ensure the building performed to its set performance objectives.

Once the building model was complete, additional data was needed to exemplify the three indices. Structured telephone interviews were performed on selected social organizations in Overland Park, Kansas to obtain the needed data for a range of organizations. The interviews provided the needed data while also validating assumptions on variable ranges and values.

The second chapter of this study provides a review of existing literature in two relevant areas, namely, community resilience frameworks and social capital studies. The review on resilience frameworks identified a lack of importance placed on social capital and an absence of a method for quantifying the various dimensions of resilience. The second part of the literature review was performed on social capital to determine its components and benefits to a community in times of normal functioning and in times of crisis. The third chapter includes the formulation for the three social capital indices. Expressions are provided for all three phases of the hazard scenario. Chapter 4 outlines the design process and selection for a performance-based designed
church, along with tested performance under a suite of seismic excitations. The fifth chapter exemplifies the social capital indices. Results are first reported for the social organizations selected for interviews, followed by a hazard scenario breakdown for those social organizations. Finally, the social capital indices are expanded to include other typical community building to demonstrate the difference in social capital of social organizations compared to the other buildings. The final chapter provides conclusions, and recommendations for further work in this area and for practical adoption of the work presented.
Chapter 2: Literature Review

A literature review was conducted over existing resilience frameworks to identify gaps within current resilience frameworks. After reviewing resilience through the lens of vulnerability, its components, and practical applications, gaps were identified in terms of the role of society in the quantitative resilience literature. A second review on social capital literature provides the background on measurable factors contributing to a community’s social capital.

2.1. Resilience Frameworks

Measuring and improving community resilience requires a plethora of resources. How much of each resource is needed, and how to distribute those resources is filled with uncertainty. Researchers spanning engineering, urban planning, sociology, geography, and public policy approach this problem through the development of new frameworks and/or computational models. This review categorizes resilience frameworks into those taking a vulnerability perspective to resilience, such as Birkmann et al. (2013), those breaking down and determining the components required for a resilient system (Bruneau et al. 2003, Baek et al. 2015, Plodinec et al. 2014), and those practically developed in conjunction with or for a community, including NIST (2015) and the City and County of San Francisco, California (2016). These three categories of frameworks are reviewed in this section, which concludes with a discussion on the gaps and how this thesis pushes the current state of knowledge forward by filling some of those gaps.

2.1.1 Establishing the Definition of Resilience

One thing most resilience studies have in common is a discussion on the definition of resilience (see Table 1). This is warranted because resilience has many definitions, all with variance based on what is being specifically studied.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abramson et al. 2015 (pg. 48)</td>
<td>Community resilience</td>
<td>Enduring capacity of geographically, politically, or affinity-bound communities to define and account for their vulnerabilities to disaster and develop capabilities to prevent, withstand, or mitigate for a traumatic event</td>
</tr>
<tr>
<td>Baek et al. 2015 (pg. 60)</td>
<td>Resilience</td>
<td>Capacity of a system to absorb disturbance, undergo change, and retain the same essential functions, structure, identity, and feedbacks</td>
</tr>
<tr>
<td>Birkmann et al. 2013 (pg. 196)</td>
<td>-Resilience</td>
<td>Ability of a system or person to deal with disturbances and the effect of stressors</td>
</tr>
<tr>
<td></td>
<td>-Infrastructure resilience</td>
<td>-Capacities of systems to reorganize themselves in the face of adverse events through processes described as revolt and remember</td>
</tr>
<tr>
<td>Cutter et al. 2008 (pg. 599 &amp; 600)</td>
<td>-Resilience</td>
<td>-Ability of a social system to respond and recover from disasters and includes those inherent conditions that allow the system to absorb impacts and cope with an event, as well as post-event, adaptive processes that facilitate the ability of the social system to re-organize, change, and learn in response to a threat</td>
</tr>
<tr>
<td></td>
<td>-Hazard resilience</td>
<td>-Ability to survive and cope with a disaster with minimum impact and damage; capacity to reduce or avoid losses, contain the effects of disasters, and recover with minimal social disruptions</td>
</tr>
<tr>
<td>Francis &amp; Bekera 2014 (pg. 91)</td>
<td>Resilience</td>
<td>Endowed or enriched property of a system that is capable of effectively combating (absorbing, adapting to or rapidly recovery from) disruptive events</td>
</tr>
<tr>
<td>Johansen et al. 2017 (pg. 1)</td>
<td>Community resilience</td>
<td>Ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change</td>
</tr>
<tr>
<td>Khalili et al. 2015 (pg. 249)</td>
<td>-Resilience</td>
<td>-A flexible response to actual danger and demonstrating an ability to “bounce back” to a previous state after a damaging event</td>
</tr>
<tr>
<td></td>
<td>-Social Resilience</td>
<td>-Ability of a community to withstand external social shock toward enhancing social capacity to resist disaster losses during disaster and regenerate after disaster, performing activities in ways that minimize social disruption</td>
</tr>
<tr>
<td>Mieler et al. 2015 (pg. 1267)</td>
<td>Resilience</td>
<td>Ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events</td>
</tr>
<tr>
<td>Norris et al. 2008 (pg. 127 &amp; 130)</td>
<td>-Community resilience</td>
<td>-A process linking a network of adaptive capacities (resources with dynamic attributes) to adaptation after a disturbance or adversity</td>
</tr>
<tr>
<td></td>
<td>-Resilience</td>
<td>-A process linking a set of adaptive capacities to a positive trajectory of functioning and adaptation after a disturbance</td>
</tr>
<tr>
<td>Plodinec et al. 2014 (pg. 10)</td>
<td>Resilience</td>
<td>Ability to positively adapt to change</td>
</tr>
<tr>
<td>Toseroni et al. 2016 (pg. 493)</td>
<td>Resilience</td>
<td>Ability of a system to adapt to changing conditions while preserving its basic structure</td>
</tr>
<tr>
<td>Winderl et al. 2014 (pg. 4)</td>
<td>Building resilience</td>
<td>Transformative process of strengthening the capacity of men, women, communities, institutions, and countries to anticipate, prevent, recover from and transform in the aftermath of shocks, stresses and change</td>
</tr>
<tr>
<td>Bruneau et al. 2003 (pg. 735)</td>
<td>Community seismic resilience</td>
<td>Ability of social units (e.g. organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes</td>
</tr>
<tr>
<td>Cimellaro 2016 (pg. 1)</td>
<td>-Engineering resilience</td>
<td>-Capability of a system to maintain its functionality and to degrade gracefully in the face of internal and external changes</td>
</tr>
<tr>
<td></td>
<td>-Social resilience</td>
<td>-Ability of groups or societies to cope with external stresses and disturbances because of social, political, and environmental change</td>
</tr>
<tr>
<td>NIST 2015 (pg. 13 &amp; 1)</td>
<td>-Resilience</td>
<td>-Ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies</td>
</tr>
<tr>
<td></td>
<td>-Community resilience</td>
<td>-Ability of a community to prepare for anticipated hazards, adapt to changing conditions and withstand and recover rapidly from disruptions</td>
</tr>
<tr>
<td>City &amp; County of San Francisco 2016 (pg. 20)</td>
<td>Resilience</td>
<td>Capacity of individuals, communities, institutions, businesses and systems within a city to survive, adapt and grow, no matter what kinds of chronic stresses and acute shocks they experience</td>
</tr>
</tbody>
</table>

**Table 1: Resilience Definitions**
From a building, or structural engineering, perspective, the words “resist” and “minimal damage” would likely be included in the definition. An ecological definition, however, would be more likely to phrase this as “absorbing shocks and resisting disturbances.” When the view is switched to community resilience, individuals and groups of people become the focus. Johansen et al. (2017) defines resilience as the “ability of groups or communities to cope with external stresses or disturbances because of social, political, and environmental change” (Johansen et al. 2017, pg. 1.). The U.S. federal government defines resilience as “as the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions” (The White House: Office of the Press Secretary, 2012), and is the definition adopted here. In order to measure resilience, resilience must be clearly defined.

The framework developed by Norris et al. (2008) made a point to differentiate between resilience and resistance. When a crisis occurs, communities are faced with a balancing act between stressors and resources. The ideal outcome is resistance, where the resources of the community outweigh the stressors. However, this outcome is often not achieved, and communities typically enter a state of dysfunction. This dysfunction is temporary, but the actual duration is dependent on how the community responds. The response is often a path of resilience, defined by stable and healthy growth post-disaster. Resilience results in a “process that produces adapted outcomes” (Norris et al. 2008, pg. 132). In most cases, there is an eventual return to pre-event functioning. However, cases exist where the community is unable to “bounce back” post-disaster, which the authors refer to as persistent dysfunction. High social vulnerability is often a defining characteristic in such cases. Norris et al. (2008) stated that vulnerability occurred when the resilient aspects of the community were not sufficient in the face of the disaster which occurred. Specific examples of high social vulnerability are provided in the next section of this thesis. Now that
resilience is understood, how resilience is achieved is examined. The first of those methodologies is vulnerability-based frameworks.

2.1.2 Vulnerability-Based Resilience Frameworks

Cutter et al. (2008) followed a vulnerability-based viewpoint in development of the Disaster Resilience of Place (DROP) model for describing community resilience. While Cutter et al. (2008) specified the difference between vulnerability and resilience, it is understood that the two are not mutually exclusive. The DROP model follows a community’s progression through a disaster or negative event. The disaster timeline begins with pre-disaster conditions based on the community’s social, natural, and built systems. Included in the pre-disaster conditions is inherent vulnerability and inherent resilience existing within the community. These pre-disaster conditions combine with the hazard event and any coping responses (either positive or negative) to define the disaster impact, or what the community actually experiences from a hazard exposure. Similar to Norris et al. (2008), Cutter et al. (2008) measured impact against the absorptive capacity of the community. If it is not exceeded, the degree of recovery is high. Degree of recovery can also be looked at through functionality. At an individual building level for example, a high degree of recovery would mean that building can quickly return to its designated function. Additionally, a high degree of recovery will also lead to a return (or perhaps even an improvement) in initial strength, so that the component is available for use when the next storm occurs. When this idea is applied to multiple buildings within a community, it will also lead to a high degree of recovery (or return to normalcy) for the community as a whole. If the absorptive capacity of the community is exceeded, the community must use its adaptive resilience. Adaptive resilience is experienced through adaptation and learning; the amount of adaptive resilience that occurs will determine the final degree of recovery. Hence, resilience is the ability of a system to respond and recover from disaster by including coping and absorptive capacities. In the Cutter et al. (2008) framework, the
characteristics available for resilience manifested themselves at many different points, namely antecedent conditions and coping responses (before the hazard event), absorptive capacity and adaptive resilience (during hazard), and finally through mitigation and preparedness (post-recovery). Combining this finding with the specification that this is a community-level resilience model, the importance of organizations and leadership groups remaining active as part of the resilience process after a disaster is clear.

The framework provided by Birkmann et al. (2013) measured vulnerability, named Methods for the Improvement of Vulnerability Assessment in Europe (MOVE), was built “to guide systematic assessments of vulnerability and to provide a basis for comparative indicators and criteria development to assess key factors and various dimensions of vulnerability” (Birkmann et al. 2013, pg. 194). The framework maps components that contribute to resilience, with a focus on vulnerability. The most commonly associated dimension of vulnerability is susceptibility. Susceptibility can come from many different components, like physical, ecological, social, economic, cultural, and institutional. Through interactions between a community and hazard events that occur, a community feels the impacts of their vulnerability during response and recovery efforts. Communities then attempt to adapt to the situation through mitigation efforts. It is important to note that vulnerability can be analyzed on an individual level, but is also dependent on place and the surrounding community. A home with low vulnerability (i.e. high income, well-educated, newly constructed home) may itself be resilient, but if it is located within a community of highly vulnerable households, that will significantly affect the low-vulnerability home.

One of the aspects of social vulnerability called out by Birkmann et al. (2013) is mental health. The resilience framework presented in Abramson et al. (2015) looked deeper at mental health by exploring its connection to resilience and recovery post-disaster, emphasizing the
importance of social resources activating the inherent resilience in community members in times of disruption. The Abramson et al. (2015) framework assumed both people and communities are inherently resilient and have a trait that will “kick in” once a stress occurs. Two key premises of the Abramson et al. (2015) framework were firstly, that access to social resources can activate resilient attributes (i.e. strong social networks have positive behavioral impacts). Secondly, resilience takes place within a person’s social environment. The second premise acknowledged the importance of culture, ethnicity, and race with emphasis on culture.

The final vulnerability-based analysis examined here bridged vulnerability-based and component-based frameworks through a five-component framework where one component was vulnerability (Francis and Bekera 2014). First is system identification, which includes defining the domain, objectives, and different characteristics. In a community, this is most often defined through a geographical boundary. The second step is a vulnerability analysis. A vulnerability analysis defines the disruptive events and their potential impacts. Similar to the Cutter et al. (2008) framework, this is done at different temporal scales, namely before, during, and after the disruption. Third, community leaders must set goals for the system’s post-disaster needs to be established. Normal system function, identified in the system identification step, is typically the goal in resilience measures and strategies that are laid out by government leaders (such as “Resilient San Francisco,” discussed later). Fourth, stakeholders must be engaged in the resilience process, as they are vital to the process and their resources and skills can make the resilience goals possible. Finally, these four components are implemented via the resilience triangle, shown in Figure 1. The resilience triangle consists of absorptive capacities (absorbing the disaster with minimal disruption), adaptive capacities (adjusting to the undesirable situations through change), and restorative capacities (returning to normal or improved operation levels).
From a review of vulnerability-based frameworks, a few conclusions can be made. First, resilience is important at multiple stages of the disaster timeline. Looking at only inherent resilience fails to capture the effect of the adaptive capacities of resilience in the post-disaster sense, as well as how community capitals such as social or political capital can increase a community’s ability to recover effectively. Though this is true, the impact of a resilience measure varies temporally. It is clear that resilience (along with vulnerability) comes from a variety of sources within the individual and the community. However, the frameworks reviewed here lack detail on how that resilience is achieved. For example, in Figure 1, resilience comes from three different capacities. However, no methods analyzing those capacities and how they relate to resilience were provided. The next section of articles covers specific components of a resilient system. With this literature, the three capacities shown in Figure 1 could be better understood.

2.1.3 Components of a Resilient System

One of the first and most widely referenced resilience studies performed is Bruneau et al. (2003). Robustness, redundancy, resourcefulness, and rapidity were defined as the four properties of resilience. Robustness is the strength of elements or of the system to withstand stress. Redundancy is the extent to which elements or systems exist that are suitable and able to satisfy requirements (i.e. the number of backups). Resourcefulness is the capacity to identify problems and mobilize local resources. Finally, rapidity is the capacity to achieve goals in a timely manner. These four properties are now referred to as the four R’s, and provide a basis for how resilience...
can be measured. In structural engineering, redundancy and robustness are often included in design, but these properties still require more research when applying them to a community. Bruneau et al. (2003) addressed what a robust community is through defining the four dimensions of community resilience as technical, organizational, societal, and economic (TOSE). TOSE dimensions can be linked to various components or elements in a community, such as the seven capitals, but a way to measure the four properties and four dimensions is still lacking.

Researchers have attempted to identify specifically what the four R’s and TOSE dimensions manifest in a community. For example, Khalili et al. (2015) examined the social dimension of TOSE identifying 14 social resilience indicators, including: community participation, education, exchanged (two-way) information, learning, shared (one-way) information, social support, sense of community, trust, demographic information, coordination, community efficacy, improvisation and inventiveness, coping style, and leadership. Khalil et al. (2015) surveyed members of two Australian communities after a flood event to identify the which indicators were most effective pre-disaster, during response, and during recovery. For example, information exchange and community participation were surveyed to be very important across the disaster timeline, education was only identified to be effective pre-disaster. Survey findings revealed that a sense of community and social support were both important through the entire disaster timeline. And while their study provided background knowledge to community leaders for making certain actions (i.e. implementing training and education to prepare for a disaster), it did not provide a way to quantify either the importance of each indicator, or the overall impact of the social dimension of resilience.

One study that was able to quantify resilience was Mieler et al. (2015) through linking resilience goals to performance targets using a four-step framework. The first step is defining key
community-performance parameters, such as undesired outcomes, vital community functions, and important systems or components. Second, leaders should establish community resilience goals with quantifiable components related to the goals. For example, say the community being studied desires less than one percent of the population to relocate because of the disaster. Step three establishes performance objects for vital community functions in an event tree, such as education or public services. Step four establishes performance targets for the systems or components important to those functions from step three, such as homes or power grids. The final analysis comes from a community level event tree, formulated to map out all possible scenarios for the given event trees described in steps three and four. The product non-desirable paths on the community level tree are then summed, aiming to keep the overall goal (i.e. less than one percent of people leaving a community or neighborhood) less than the summed products. Their study provided a step in the quantitative direction in terms of measuring resilience through setting performance objectives, which allowed for it to be used by government leaders. Mieler et al’s fault tree analysis methodology provides a step forward in how to quantitatively measure and improve a community’s resilience. The proof of concept example considered four variables (residents displaced, businesses disrupted, students displaced, and public service capacity disrupted), capturing the portions of the social and economic dimensions (the two dimensions relating to a community’s ability to withstand or recover from a disaster) articulated by Bruneau et al. (2003).

Interwoven with the TOSE dimensions from Bruneau et al. (2003), Cimellaro et al. (2016) provided a method for evaluating a community’s resilience measured using seven dimensions (population and demographics, environment and ecosystem, organized government services, physical infrastructure, lifestyle and community competence, economic development, and social-cultural capital) formulated into the PEOPLES framework. Each dimension has
components and subcomponents. For example, some of the social and cultural capital components include cultural and heritage services, education services, non-profit organizations, and place attachment. Cimellaro et al. (2016) also provided a measure for quantifying the seven dimensions, but limited the measurement to a single variable for most dimensions. When discussing measurement for the social and cultural capital dimension, the authors provided six components for measurement, namely volunteerism, association in social groups, political participation (such as voting), religious participation, community attachment, and connection to working places. While these measures are at an individual level, rather than a full community, they do provide a general idea of what social capital measures attempt to capture.

By combining facets of many different resilience frameworks, such as the 4 R’s from Bruneau et al. (2003) and dimensions similar to PEOPLES from Cimellaro et al. (2016), Toseroni et al. (2016) developed a methodology to determine if a community is resilience or not. The Holistic Community Resilience Assessment Method uses a flow chart which begins by asking if the system’s coping capacity is sufficient for the hazard at hand. If not, the community is analyzed based on resilience dimensions (such as economic, environmental, institutional, infrastructural, and social) and disaster phase management practices (namely, mitigation, preparedness, response, and recovery) within a community to formulate a set of indicators. Those indicators are weighted and analyzed to formulate a resilience index. If the coping capacity is still insufficient, the framework recommends evaluation of the system through the lens of the 4 R’s. When evaluating the index, data is standardized, thereby allowing for the critical or effective processes to be identified. The authors comprehensively presented a number of important variables of a resilience index, as well as how those variables worked together in a community setting. However, a gap exists in how those variables or dimensions are quantified.
Due to the growth of resilience as a research topic, both Winderl et al. (2014) and Johansen et al. (2017) delivered summaries and discussions on the vast array of current resilience frameworks. Winderl et al. (2014) summarized existing methods and frameworks for measuring resilience. Typical measurements use four important components: elements, levels, dimensions, and units of analysis. Elements are what is actually being measured, including items such as well-being, vulnerability, capacities, stresses, reactions, and program results. Levels are the reaction chain involved, for which four are listed, namely inputs, outputs, outcomes, and impacts. Dimensions, which would be similar to the PEOPLES framework (Cimellaro et al. 2016), included physical, human, and social dimensions. Finally, the different units of analysis, which is often measured geographically, can be as small as an individual household or a global scale. Resilience measurements also have certain defining characteristics, such as being standardized or context specific, actual measurement or model, among others.

Further, Johansen et al. (2017) provided a summary of the existing metrics for measuring resilience. Metrics fall into three categories of resilience, namely community-level, sector-specific, and sociological. Community-level resilience metrics find what works for each individual community through local objectives and partnerships. Sector-specific resilience metrics measure specific components of community, such as infrastructure, buildings, or other critical assets. Finally, sociological resilience metrics connect the adaptive capacities of a community to responses and changes due to the adverse events (i.e. high hazard vulnerability with strong social networks and planning could be more resilient than a community with low hazard vulnerability and weak networks). All metrics are somewhat limited individually, but are most effective when combined. The articles reviewed above provide the theoretically important components of
resilience. The next section reviews practical realizations of community resilience frameworks that have actually been adopted by or developed for real communities.

2.1.4 Practical Resilience Frameworks

Due to the growth of resilience and the desire to implement it in communities, research has been done on step-by-step programs for improving resilience for utilization by governments, stakeholders, and other decision makers. Plodinec et al. (2014) based their strategic planning approach on the Community and Regional Resilience Institute (CARRI) Whole Community approach. The Whole Community approach believes if an entire community is affected by a disaster, then the entire community should be involved in planning for disaster preparation and response. The community splits up into core services to ensure all groups are accounted for and there is adequate understanding of the linkages between each. Plodinec et al. (2014) listed six steps for resilience planning, focusing on whole community action. First is organization, which involves defining the community and its leaders. Assessment is next, where leaders are tasked with evaluating the community and its current resilience. Third, the leadership team sets goals and creates a vision, while taking input from the community. After that, the leadership team creates action steps to make those goals a reality. The fifth step is to implement those actions. Once the plan has been set in place, the final step is to monitor and evaluate the plan’s performance. While the individual steps aimed to improve resilience in communities, it is important to note that strong resilience action requires the use of the entire community. The entire community encompasses not only homeowners and government leaders, but also the business owners and other leaders, as well as the organizations they are involved with.

Continuing on the Whole Community approach, Baek et al. (2015) presented similar steps, but through a socio-technical viewpoint. Social and technical systems are separate but
The social system involves members who are generating and enriching relationships, while the technical system carries out tasks to reach specific goals. The first step is analysis, which includes defining system scope, analysis of the existing system, problem diagnosis, and objective setting and strategy building. Through these four services, a more resilient system (or community) can be designed. The third and fourth steps are implementation and evaluation. The steps of analysis and evaluation are part of the social system, where leaders and stakeholders are directly involved and are influencing the design and implementation steps. Design and implementation, on the other hand, is the technical system. Implementation influences the overall state of the social system. Hence, the two systems are uniquely and importantly intertwined. The study by Baek et al. (2015) changed the outlook of the social system in resilience interventions, as it can act as both an input and an output. The framework presented was aimed “at transforming the social system state through the design of a technical system, which in turn requires an understanding of the social system” (Baek et al. 2015, pg. 78). Hence, resilience turns into an iterative process between social and technical systems. This requires leaders and organizations involved in both the technical and social aspects of a community to be involved throughout resilience planning.

Compared to mitigation, one often forgotten aspect of resilience planning is the recovery actions. To address this, the National Institute of Standards and Technology (NIST) wrote a special publication to assist government leaders in planning for the recovery aspect of resilience. Their six-step process for community resilience planning is as follows. First, a collaborative planning team is formed from various government leaders, businesspeople, or anyone representing a large portion of people. Second, the team analyzes the current situation of the community’s social dimensions and building environment. Next, goals and objectives are formed through identification of needs, risks, and opportunities. Fourth, a resilience plan is developed through the
solution of gaps between desired and anticipated performance. The fifth step is preparation, review and approval of step four’s plan. As Francis and Bekera (2014) pointed out, community engagement is important in this process, so review and approval is not done solely by the design team, rather it must also involve the people that will use and depend on the finished product. Finally, the plan is implemented and maintained as needed. The idea of social functions driving the built environment in a resilient community is a driving premise for NIST (2015).

San Francisco developed a resilience strategy called “Resilient San Francisco” (City and County of San Francisco, 2016) to address the issues of a growing city located in a high seismic region and dependent on bridges for entering and exiting most areas of the city. “Resilient San Francisco” included four actionable goals to face current and future challenges. The first goal was planning and preparation for the future by building the city’s capacity to handle any challenges. Second, the infrastructure would be mitigated, adapted, and retrofitted to confront hazard realities. The third goal was ensuring housing for citizens inside the city boundaries, especially post-disaster. Finally, “Resilient San Francisco” called for empowerment of neighborhoods by improving social connections through “building on the strength of the city’s vibrancy and character” (City and County of San Francisco, 2016, pg. 11). Each of these four actionable goals included more specific sub-goals, such as advancing in earthquake preparedness, mitigating local climate change, and improving access to government (e.g. improving social capital). Additionally, each of the four goals included key indicators to measure the city’s progress quantitatively, such as 180,000 retrofitted homes by 2025 or housing 8,000 homeless people by 2020. “Resilient San Francisco” provided a real-world example of what actions were being done to increase resiliency in a city, that can be utilized by other communities moving forward.
It is clear that resilience research is now a large topic. It has grown exponentially, covering a wide variety of topics. Starting from definitions of resilience, literature expanded and dove into what made up resilience. This includes various characteristics and dimensions, both at the individual building (or similar component) level, as well as up to the community scale. Once resilience aspects were determined, instruction and recommendations for increasing resilience became available and pushed the idea of resilience further.

However, gaps still exist in community resilience, largely due to the depth and expanse of the topic of resilience. Resilience is a wide, far-reaching topic, as it includes many different dimensions, and therefore requires the work of a large number of professionals. For example, the PEOPLES framework (Cimellaro et al. 2016) includes seven different dimensions of community resilience just like NIST (2015) refers to seven capitals inherent in a community, all requiring the expertise of different professions. Hence, creation of resilience measures or frameworks is often simplified in many of the dimensions, and therefore make the framework lack a certain accuracy.

One dimensions noted in some of the studies referenced above was the social or cultural aspect of resilience. As shown in the practical resilience frameworks, this has importance as communities work together to develop an effective resilience solution. Studies like Birkmann et al. (2013) and Cimellaro et al. (2016) call out society and cultural as important dimensions of resilience framework, but focus on other dimensions or the connection across all dimensions. Due to the important role that society and culture play in communities, specific and focused research is needed. Much of the research on the social dimension, when included, looks at individual-level measurements, such as trust, participation, crime rates, or voter participation (seen in Khalili et al. 2015). True social capital is the networks of relationships between people of a specific area, and how those connections are cultivated. It is more than just trust; it also encompasses strength of
relationships and cohesion, the feeling of culture and community, and overall importance of being connected. Positive social capital has a positive effect on resilience, both at an individual level but especially at the community scale. A community with high social capital will function better in the pre-disaster setting through happier members or lower crime rates, and will recover more effectively post-disaster. This study aims to solve the final two gaps mentioned, namely by accounting for social capital in resilience frameworks and the lack of a way to measure resilience and its components.

2.2. Social Capital

The first step to adequately account for social capital is to define exactly what social capital is and to find what components within a community are relevant to social capital. One important aspect to this is the depth of relationships, which is captured by Nakagawa and Shaw (2004) through bonding, bridging, and linking social capital. These three types of social capital are covered later. Social capital can be grown through organizations and interaction between community members. Glanz (2011) and Carpenter (2013) showed how community layout can have an impact on this as well. For example, mixed-used buildings that have restaurants on the bottom story and residential units on the top, or providing parks in the middle of large neighborhoods, bring people closer together by getting them closer to shared spaces manifesting more social interaction. After the important aspects of social capital are identified, the benefits of social capital in day to day life, such as sense of community or trust is reviewed. While these studies show social capital is important in a healthy community, one area where social capital has another significant impact is in the post-disaster setting. A series of case studies reviewed here demonstrate bridging and linking social capital in a post-disaster setting; no articles were found to measure bonding social capital post-disaster. The review of social capital benefit case studies is followed by further
case studies of the aid provided by specific organizations in disaster-affected areas and how this aid built social capital.

2.2.1 Social Capital Definition

Buckland and Rahman (1999) defined social capital as the “features of social organization, such as trust, norms, and networks, that can improve the efficiency of society by facilitating coordinated actions,” going on to say, “social capital conceptualizes the capacity of a community or society to organize in order to achieve an intended result” (Buckland & Rahman, 1999, pg. 175). Social capital can also be looked at as the bonds which tie citizens together (Aldrich, 2010). Meyer (2013) noted that social capital has the capacity to make a community a community, has the potential to meet vulnerable population’s needs, represent collective action, and demonstrates how the community is more than merely the sum of its parts. Positive social relationships can be beneficial for vulnerable individuals both in daily life and post-disaster. Tierney (2014) pointed out how strong social capital manifests itself within a community through a variety of ways, such as feeling of mutual trust, a common vision for community life, social participation, and community engagement.

As Tierney (2014) pointed out, social participation and engagement is one way that social capital is manifested within a community. However, social capital also requires participation and engagement from community members. Community members can participate in organizations like religious organizations, resident associations, or neighborhood watches. Through participation in these organizations, members experience a sense of community, which is manifested through shared values, a sense of trust and respect, or fulfillment of certain needs. Participation also provides a sense of community, or an emotional connection to the neighborhood itself, which further provides stability. Additionally, having set roles and responsibilities (specifically within
organizations) through leadership, teamwork, and relationship management demonstrated to have a positive effect on community resilience and individual health (Norris et al. 2008).

In one study, a church being studied was said to be “the hub around which spiritual, social, and commercial life evolved” (Chamlee-Wright & Storr 2009, pg. 433). Because these bonds or connections are typically more qualitative in nature, they lend themselves to difficulties in measurement. However, just like physical or economic capital, social capital is able to function “as a public good...that is, a resource which provides nonexcludable benefits, so that all residents of a high social capital neighborhood enjoy its positive side effects” (Aldrich 2011a, pg. 3). Another way of referring to these benefits would be club goods, defined as items and actions that assist and affect the community they are a part of (Chamlee-Wright and Storr 2009). Social organizations that develop close relationships and a shared vision within a community have a direct impact for its users.

All benefits of social capital are important for community resilience. However, a distinction needs to be made between the different types of social capital. As social capital is predicated on relationships and connections built, the depth of those relationships has an impact on the benefits that come from social capital. Nakagawa and Shaw (2004) discussed three categories of social capital. First is bonding social capital, which is between immediate family and close friend; bonding is the strongest type of social capital, and is generally the most impactful in a person’s life. Bonding relationships are typically the deepest, and based on years of interaction. The second type of social capital is bridging social capital. Bridging social capital typically exists between people who would be considered “acquaintances.” These connections are independent of a person’s ethnic, geographic, economic or occupational background. Bridging social capital typically stems from places of employment or within social organizations. Because bridging social
capital is typically based on a single common bond between people, these relationships are not as deep or important to an individual as bonding social capital. The third type of social capital is linking social capital. Linking social capital is with those who have influence in formal organizations like governments or banks. People in these relationships will likely have different economic or occupational standing, and will likely not know each other. However, their connection is important in terms of vulnerability. Bonding and bridging social capital increases a person’s network, attempting to offset vulnerability through increases in social capital. Linking social capital attempts to eliminate vulnerability and improve the livelihood of community members.

2.2.2 Social Capital and the Built Environment

As was noted above, one of the ways to increase social capital is through relationship building and increased interaction. One way this can be accomplished is through the built environment and how communities are laid out (Carpenter 2013 and Glanz 2011). Specifically, Carpenter (2013) examined “the potential for creating cities that are more resilient by creating spaces that foster social networks” (Carpenter 2013, pg. xiv), and created a measure of community resilience. Urban planning research has shown the built environment influences social capital. For example, walkable and mixed-use neighborhoods can increase the probability of social and accidental interaction between community members. The built environment can act as an anchor to everyday habits, carry a collective memory for the residents, or manifest sense of identity. Additionally, participating in social organizations promotes trust and increases social capital. These organizations can be religious, political, economic, educational, and many other types. Further, these organizations are also often able to form impromptu relief and recovery teams, regardless of whether they have participated in official relief training. To create the community resilience measure, Carpenter adopted six built environment variables that affect social capital:
land use mix, housing density, intersection density, social gather place density, parks and open space density, and historical site density. The first three measure the probability of social encounters, the next two measure places that promote social gather, and the final increases place attachment. By performing a case study in the Mississippi Gulf Coast post-Katrina, Carpenter found that local networks were effective in increasing resilience. Low-resilience communities were generally connected to state, national, military, and federal organizations. High-resilience groups, on the other hand, tended to have better connections with non-profits, schools, businesses, and municipal organizations. Both had strong ties to faith-based organizations. Also included throughout were commercial establishments, such as retail, restaurants, bars, casinos, movie theaters, and barber shops. These were places where people congregated and were seen as important by residents. These establishments served as a way to stimulate local activity, increase interactions, and facilitate organizational activity.

Glanz (2011) mentioned how the layout of communities which incorporate elements such as porches on houses and street furniture encourage and facilitate human interaction. Glanz (2011) also differentiated between macro- and micro-scale features. Generally, macro-scale is how the neighborhood is laid out (e.g. street length) and micro-scale is what fills the neighborhood (e.g. sidewalks and street amenities). Macro-scale and micro-scale features affect how a resident perceives their environment in terms of safety, pleasantness, and accessibility. One relevant variable included by Glanz (2011) is sidewalks and walkability. A community with relatively square blocks and natural (and well-kept) sidewalk paths will allow for “accidental socialization” between residents. The same is true of higher density communities, concentrated retail cores, and dedicated public spaces. Any accidental interaction between community members can create more bridging social capital between community and/or organization members.
2.2.3 Benefits of Social Capital

As social capital is grown within a community, it has positive impacts in daily functioning through increased trust or social participation. The effects of social capital, especially bonding and bridging, have an immense impact in the post-disaster setting. Dynes (2005) found that while social capital has been studied in community groups like family, school, and business, it has never been applied directly to post-disaster response. During the disaster phase social capital “is less damaged and less affected. Consequently, during the emergency period, it is the form of capital that serves as the primary base for a community response. In addition, social capital is the only form of capital which is renewed and enhanced during the emergency period” (Dynes 2005, pg. 7). While social capital is difficult to present or measure, it can serve as a basis for community response, and also can be improved or grown through the course of a disaster or emergency period. Studies referenced in Dynes (2005) showed that members in a community do not rescue victims at random. Rather, participation by community members was related to the strength of their existing relationships with the victims. In fact, the chance of survival was proportional to the presence of relief workers who knew the victim (and potentially their location as well). Further, existing organizations were able extend their activity through disaster tasks. Specifically, groups originally concerned with community service saw “disaster-related activities as a logical extension of their previous orientation” (Dynes 2005, pg. 31). Examples of disaster-related activities could include construction crews removing debris, church groups providing temporary feeding and emergency shelter, or Boy Scout troops as messengers. Examples like these are significant in terms of the benefit of social capital provided by social organizations, and were vital in development of the indices in Chapter 3. The substantial social resources within social organizations and
infrastructure allow these groups to mobilize quickly post-disaster, aiding in overall community functionality and recovery.

While Dynes (2005) noted the importance of these organizations in the disaster sense, Norris et al. (2008) portrayed that effective social capital requires participation by community members in these groups. The authors pointed out that during a disaster, the entire community tends to feel stressed, not only the individuals directly impacted by the disaster. Communities have shown after a disaster there are “tendencies for residents to feel less positive about their social networks and surroundings, less enthusiastic and energetic, and less able to enjoy life” (Norris et al. 2008, pgs. 133-134). To counteract this, the authors pointed out how citizen participation is a fundamental element for community resilience and helping the citizen return to a normal life post-disaster. Repeating what was mentioned above, participation leads to a shared sense of community, shared vision, and a fulfillment of member needs. Community members who have built social capital, especially those with high bonding social capital, will have a greater number of positive interactions and experiences in the face of the disaster.

Further, Meyer (2013) noted how social capital has two components, the network built and the resources available through them. These resources are both financial and nonfinancial. In the post-disaster setting, nonfinancial resources can refer to resources such as search and rescue, childcare, shelter, and others. While these resources are available between linking social capital connections, there are much more effective from bridging connections. These connections will likely come from a smaller group of people than the government (in linking social capital) and any action will be able to be put into motion quicker, as in Chamlee-Wright and Storr (2009).
2.2.4 Linking Social Capital Case Studies

Numerous studies have investigated the beneficial characteristics of social capital, looking specifically at different people groups affected by disaster. These studies, similar to Carpenter (2013), used variables that focused on the level of participation in community events and organizations to quantify social capital. While these are not totally incorrect, they only capture a small part of what social capital is by only accounting for linking social capital.

Buckland and Rahman (1999) used two variables, the density of civic engagement and normative behavior in the public sphere, to measure social capital, and tested whether they increased community disaster management in three communities after the Red River Flood near Winnipeg, Manitoba, Canada. The three communities were a Native-American community, a German-speaking Mennonite community, and a French-speaking Catholic community. The Native-American community was economically and socially marginalized, with prevalent child abuse, suicide, violence and vandalism. The Mennonite community was very focused on communal living and mutual aid, while the Catholic community was considered the baseline community. In terms of civic engagement and development level, the study showed that the Mennonite community ranked highest, with the Native-American community ranking the lowest. The Mennonite community was the most prepared, and performed the best post-flood. It was also pointed out that over half of the Mennonite community members were involved in flood preparation, and had very high number of faith-related organizations aid in post-disaster relief. Overall, both the Catholic and the Mennonite communities responded effectively to the flood, while the Native-American community had a relatively low level of progress in repairs.

Klinenberg (2002) examined two nearly identical communities impacted by the 1995 Chicago heat wave. The only significant difference between the communities was the number of
deaths caused by the heat wave. The community with high mortality rates had poor social capital, including a high number of abandoned buildings, high crime rates, and population decline. In contrast, the low-mortality rate community had a vibrant street life, high population density, and easy-to-attend social functions. Again, this study only captures the effects of linking social capital.

Nakagawa and Shaw’s 2004 article, “Social Capital: A Missing Link to Disaster Recovery,” is a statement in itself. The article stated that idea of social capital helping post-disaster transitions is no longer new, but the idea that social trust and social norms can be measured (which can positively affect social, political, and economic performance) is new. “Civic-ness,” a term used by the authors, was used as a measure of horizontal associations with four indicators: newspaper readership, sports and cultural clubs, meeting turnout, and voter participation. To examine the effects of social capital measurements, Nakagawa and Shaw collected data on communities after the Kobe earthquake. Gray zones, areas which a recovery organization was formed but got no funding, often had poor performance. One gray zone, however, had a community that rallied around them. Local and community firms helped put out fires, schools served as emergency evacuation locations, and a community kitchen was established. Because the community stepped up, the recovery organization was able to perform inspection surveys, write newsletters informing the public, and retrofit damaged houses. The community had trust in each other from previous social interaction, often due to community programs like sports leagues and festivals. The same was shown for another town after the Gujarat Earthquake. The Soni group rebuilt the quickest, despite low income levels, due to their investment into the community. Pre-earthquake, they held community festivals to raise money for the community, ran youth groups, and provided financial support for suffering families through shelter and medical assistance.
Aldrich (2010) stated, “Recovery from natural and other disasters does not depend on the overall amount of aid received nor on the amount of damage done by the disaster; instead, social capital, the bonds which tie citizens together, functions as the main engine of long term recovery” (Aldrich 2010, pg. 1). This was shown through the lens of three disasters, Hurricane Katrina in New Orleans, Kobe Earthquake in Japan, and a tsunami in the Indian Ocean. The Kobe disaster was the costliest disaster, with the tsunami being the least. Additionally, the per capita income of the Indian people was around 40 times less than that of the Japanese and New Orleans residents. However, amidst the large monetary advantage New Orleans had, they recovered much slower than the Asian disasters. Studies of African, Asian, and Central American communities after a disaster have shown that new or improved bridges, roads, and buildings did little in long-term recovery, which was used to advocate for more policy implementation in the area of social capital.

2.2.5 Bridging Social Capital Case Studies

Aldrich (2011a) provided three reasons for why a community with denser and wider networks will recover quicker than one without. The first was that strong social ties can serve as “informal insurance,” or groups that support physically and financially, or that pass along essential information. Second, these communities overcame barriers through collective action and controlling resources. Finally, social networks raised the cost of exit from a community, meaning that people cannot easily replicate their social attachments in new or different places. Aldrich’s findings were consistent with the other literature, namely that positive social networks increased the rate and quality of recovery post-tsunami. It was shown that local organizations were the only institution providing continuity. For example, leaders of the local organizations were able to talk with villagers and provide the government with a list of needs. Aldrich also discussed how social capital provided more robust mental health, greater access to logistical and financial resources,
and reduced the need for counseling and overall external intervention. Leaders of social organizations also served as mediators with the aid community during relief efforts.

Again, Aldrich (2011b) referenced the perceived impact of bridging or bonding social capital. In this article, it was noted how people that evacuate may return home, but only with a “wait and see” attitude. This approach would mean that evacuees would see if other neighbors, schools, churches, and more community components would return before they returned. In contrast, businesses may be deterred from reopening if community members do not return, as their business profits will be hindered. However, a community that has strong institutions which provide norms and networks to community members has shown to respond positively to this collective community issue. A neighborhood’s social capital reservoirs can be necessary components to recovery. Both Aldrich (2011a) and (2011b) showed that social capital is a way to combat and counteract social vulnerability. Cultures with high social capital and high social vulnerability were shown to recovery faster than groups of people with low social capital and low social vulnerability after Hurricane Katrina. While there exists a large amount of research on social vulnerability measurements, a gap exists for measuring social capital and its effects on vulnerability.

In a 2014 article on social capital and resilience, Aldrich and Meyer noted how common responses to risk is to strengthen physical infrastructure and building codes. An alternative approach for pre-disaster mitigation and recovery is to strengthen the social infrastructure that directly affects community resilience is presented. Studies on the Kobe earthquake showed that the first responders to those trapped under rubble were typically their neighbors. Neighbors and others with informal ties to community members checked on the wellbeing of their friends and family after the disaster, and many times quicker than emergency services due to overload. This was one of the many examples that showed how built relationships could translate into tangible
resources for individuals. The authors provided two methods of measuring social capital, measuring the attitudinal and cognitive aspects or behavioral manifestations of social capital. The first included asking for a person’s general measure of how trustworthy or honest their community members are. The latter asked questions about whether people leave their doors unlocked, what clubs and groups they are members of, and how many neighbors they know. Studies that measure the behavioral manifestations have been performed in the past; the most commonly used is the National Social Capital Benchmark Community Survey from Harvard in 2000 and 2006. Because of these studies, some change has come in the area of social capital. Three changes, time banking, focus groups and social activities, and community layout are provided. Time banking encourages people to get out into the community and rewards people for volunteering. Social events such as parades, block parties, community gardens, mentorship programs, and local sports leagues have all been implemented into communities post-disaster as a way to increase social cohesion. Finally, community layout is rearranged to maximize human interaction. Per Aldrich and Meyer, “Interaction can occur in areas where residents can meet and spend time, however short, together...Coffee shops, bookstores, bars, hair salons, public squares, and libraries serve as third places for social capital to be generated and regenerated” (Aldrich & Meyer 2014, pg. 10).

2.2.6 Social Capital from Organizations

The final set of articles reviewed here discussed case studies of disasters, but give explicit examples of the structures of the social organizations that made an impact after a disaster hits a community. In his 2005 article titled “Ritual in the ‘Church of Baseball,’” Michael Butterworth discussed the role of baseball after the 9/11 terrorist attacks. Sports arenas, specifically baseball stadiums, along with government speeches and prayer services, served as places and events of memorial. Because of how the American culture values baseball, Butterworth contended that
baseball had a responsibly to respond after the attacks. He noted, “Since baseball is so often viewed as a symbolic expression of what is American, its role extended far beyond simply healing, or providing a diversion” (Butterworth, 2005, pg. 109). Additionally, the author equated sporting events to a group catharsis post-disaster. When the games restarted after five days off, they were seen as an antidote because they were able to take the focus of the people off of the tragedy. The same has been shown in various other cities, such as New Orleans after Hurricane Katrina with the Saints football team.

Chamlee-Wright and Storr (2009) presented the impact of one of these social organizations in the Lower Ninth Ward of New Orleans after Hurricane Katrina. The Mary Queen of Vietnam (MQVN) is a neighborhood defined by a catholic church of the same name, and was in one of the hardest hit regions after the Hurricane. Nevertheless, the MQVN neighborhood rebuilt much faster than most of the other neighborhoods in Orleans Parish, even those with similar levels of flood damage. The authors found this was primarily due to the MQVN Catholic Church. The church provided what the authors called “club goods” to assist the community in rebuilding their ethnic and religious community. The days during Katrina, 500 community members found emergency shelter inside the church. After Katrina, the church remained central to the people of the community. They provided the typical religious services, but a host of other events as well, such as language training, weekend markets for arts and crafts, and hosting meetings for both religious and nonreligious groups. The church also served as a distribution center for necessities like clothes, blankets, food and water. Additionally, the leadership provided an important role as a bridge between the residents and insurance companies or government relief agencies. In an interview, the pastor called the church the anchor, noting its importance for keeping people in the community.
Chamlee-Wright and Storr (2011) indicated out how social capital can enable community return. Even if a community is lacking the specific resources needed to completely rebuild, positive social relationships can create the perception of a resilient community, which will prevent them from emigrating and make the community more resilient. More resilient communities are more efficient in rescue, relief, and recovery work post-disaster, as well as having a more improved attitude. On the other hand, for those who see their community as not very resilient, the most rational option is to leave and not return or rebuild. An example of a resilient community after Katrina was the St. Bernard community, described as both family-oriented and close-knit. St. Bernard had active Kiwanis and Rotary clubs and well-attended high school football games on Friday nights. One resident said, “If you go by Chalmette High on a Friday night, everybody [is] there watching the football game. That’s just how it was, everybody knows everybody” (Chamlee-Wright & Storr, 2011, pg. 276). Many people stayed in the area and chose to rebuild “because they could not replicate their social networks elsewhere.” Because of their close-knit relationships, the community functioned as a symbol of who these people were, a dominant attitude in how people viewed the disaster, and a catalyst for rebuilding and progress.

Tierney (2014) also noted how social capital acts as a buffer for disaster-related stresses and promotes community recovery. Tierney pointed out the little emphasis placed on the resilience of the critical cultural infrastructural, referred to here as ‘social infrastructure,’ and include faith-based and community-based groups that provide for vulnerable populations in times of crisis. These faith-based or community-based groups can provide aid through a number of ways, such as emergency aid, case management, human services, or housing assistance. Tierney also referenced how these places are not typically prepared for disaster relief experience. Their improvisation to help is positive for the community, but they also tend to lack the resources to continue and are
stretched beyond their limit to help. Government leaders and policymakers were encouraged to help community-based organizations be prepared for disaster, consistent with FEMA’s whole community approach. Typical disaster response overlooks the need to restore social capital, rather than prioritizing reconstruction of entire neighborhoods through restoration of parks or rebuilding faith-based and community-based organizations.

In 2016, Triplett wrote an article for ESPN, ten years after the historic football game between the New Orleans Saints and Atlanta Falcons. After Hurricane Katrina, the Saints stadium, the Superdome, provided emergency shelter until the roof was damaged and had to close. The reopening of the stadium and the return to football “became a symbol of the city’s rebirth after the devastating storm” (Triplett, 2016). While many feared they would never be in the Superdome for a football game again, the Saints head coach noted the symbolism the game carried of rebirth and getting New Orleans back to normal. One Saints player noted how the night was bigger than just football for the city, while another said that the strength and resilience of the team represented that of the city during and after the hurricane. During the game, the commentator later reflected how during the game, he chose to say, “Touchdown New Orleans,” because it was a touchdown for the entire city, not just the team.

Reverend Johnson, the Director of the DHS Center for Faith-Based & Neighborhood Partnerships, encouraged the faith community to act in times of emergency management. He noted that after Hurricane Sandy, faith-based and non-profit organizations provided information, meals, supplies, medical care, public safety, and more. These groups exceeded their primary role and “addressed the immediate needs of at-risk residents and communities-at-large in the critical 72-hour period following the storm” (Johnson 2017). Johnson continued by saying that an emergency should be a church’s finest hour, and that the church should be a symbol of hope for the city. While
the government should do their part, faith-based organizations should also feed, clothe, comfort, and house those who are affected.

Social capital is growing in importance, but a gap still exists between resilience and social capital. It is understood that strong social capital increases resilience. It is also accepted that social capital is a part of resilience. Yet there is currently no way to quantifiably connect the two concepts. This study aims to develop indices for measuring the social capital that is experienced or built by social organizations, such as churches, libraries, and museums. With this framework for quantifying social capital, decision makers will have concrete evidence of the importance of social capital, along with a way to utilize that social capital in ways that will further community resilience. This is explored further in Chapter 3. Another way that social capital could be used to improve community resilience is through stronger design of structures that house these social organizations. This second motivation is discussed further in Chapter 4.
Chapter 3: Social Capital Model

As mentioned in Chapter 2, one goal of this study was not only to be able to call attention to social capital and its importance in resilience frameworks, but also to provide a way to measure social capital. The resilience framework from Figure 2 shows the impact of including and measuring the impacts of social capital within a community. The three numbered steps (pre-disaster conditions, hazard event, and recovery) represent the general progression of community resilience through a hazard scenario. When community resilience is only focused on capitals such as physical (strength of facilities or lifelines) or economic, community functionality behaves like the thin, black line of the graphical representation below the framework. Physical and economic capitals are typically the only capitals used because they lend themselves to quantification, through fragility curves and building performance (physical) or dollars amounts (economic). When simply these two capitals are analyzed and used for community resilience, community functionality will be less likely to return to pre-hazard conditions. When this occurs, government leaders and decision makers should evaluate current practices and interaction of community capitals based on their robustness, redundancy, resourcefulness, and rapidity (the four R’s). On the other hand, if social capital is included in community resilience, literature shows that a community will be more likely to return to or even exceed the initial conditions. As shown in Figure 2, social capital affects both the drop due to the hazard event of the community as well as recovery capabilities. This is also shown in the graphical representation with the thick, lighter shaded line. The initial impacts to the hazard are lessened, and the rate and quantity of recovery are amplified.
Figure 2: Resilience Framework Including Social Capital

Economic Capital
Physical Capital
Human Capital
Political Capital
Cultural Capital
Natural Capital

SOCIAL CAPITAL

Community Resilience
Pre-Disaster Conditions
Hazard Event
Recovery

Return to or exceed initial conditions?
YES: Good
NO: Evaluate capitals in terms of 4 R's

Community Functionality
Time
Some of the infrastructure within a community that develop the greatest amount of capital are social infrastructure, or infrastructure directly involved in building relationships and growing social capital. In order to measure the impact of social infrastructure in social capital (and further, resilience), three indices were developed: one to measure the social capital of the organization housed within the infrastructure, another to measure the social capital provided by the building itself, and a third to measure the number of interdependencies that social infrastructure has with critical infrastructure within the community. While the focus of this study was on social organizations initially, these indices can be applied to typical community buildings as well, as is shown in Chapter 5.

The framework for this study is provided in Figure 3. By obtaining characteristics of social organizations and infrastructure, the framework outlines a method for calculating the social capital within that organization. The three indices are the first step of the social capital model. This chapter presents the variables utilized in the development of the indices, first for the organization, followed by the building, and finally for the critical infrastructure interdependencies. Rationalization and supporting literature for each of these variables is provided, as well as the methodology of combining the variables into three index measurements.
Figure 3: Social Capital Index Research Framework

INPUT

1) Pre-Disaster
2) Hazard Event
3) Recovery

HAZARD SCENARIO

INDEX-BASED ANALYSIS

OUTPUT

Mitigation and Recovery Prioritization Strategy

Make recommendations

Organization Characteristics
Building Characteristics

Organization Social Capital Index
Building Social Capital Index
Critical Infrastructure Interdependency Index

INPUT

INDEX MEASURE

SOCIAL CAPITAL MODEL

Calculate social capital index values for typical community buildings

Compare across community and buildings

Compare across hazard scenarios

Critical Infrastructure Interdependency Index

INPUT

INDEX MEASURE

SOCIAL CAPITAL MODEL

Calculate social capital index values for typical community buildings

Compare across community and buildings

Compare across hazard scenarios

Critical Infrastructure Interdependency Index
The next section of the social capital model includes analysis based on hazard scenario. As noted in social capital literature (e.g. Chamlee-Wright and Storr 2009), social organizations can also have an immense impact in the post-disaster setting. Hence, the indices were altered based on three different phases of a hazard scenario: (1) pre-disaster conditions, (2) the hazard event, and (3), the recovery period. The next section of this chapter discusses the altered equations variables.

The final section of the social capital model, labeled Index-Based Analysis, applies the social capital model to the broader context of a whole community. While social organizations like churches or museums may have the largest impact on social capital, typical community buildings like single-family homes, office buildings, and retail stores will also impact the social capital of the community. The calculation at this step provides a concrete example of the importance of these infrastructure in a community setting. Further, allowing for the calculation of the social capital index to be utilized on all building archetypes furthers the ability to measure the resilience of a community as a whole, as was modeled in Figure 2.

3.1. Organization Social Capital Index

As shown in Figure 3, the first step of the social capital model is formulation of the social capital indices. Social capital can form through an organization through relationships fostered by way of the organization, such as small group capability or regularly scheduled events, and through any adaptive post-disaster functions or services offered by the organization, such as community-centered events. The organization social capital index consists of a number of variables and metrics whose incorporation and measurement is grounded in the literature, and are described as follows.

*Membership Number* measures the number of people included in the membership program by counting each individual member. Membership includes the number of regular users, active members, and those who rely on the organization. Connections to an organization provide
support through membership activities and informal ties between members (Aldrich and Meyer, 2014). An organization that engages with more people will have a greater importance within the community, and therefore should be prioritized. In terms of the three types of social capital (bonding, bridging, and linking), this allows for people to build a relationship between like-minded people or individuals with similar interest, developing bridging social capital. In terms of measurement, membership number is obtained as a quantitative value already. However, because the number is large (in the hundreds or thousands) it is normalized to fit the rest of the data. Hence, the value was taken and normalized against the maximum membership value of the applicable organizations being investigated, expressed as

$$\alpha_M = \left( \frac{\text{Membership number of specific organization being studied}}{\text{Maximum membership of all organizations being studied}} \right)^{0.25} \quad (3.1-1)$$

Raising the normalized membership number to the 0.25 power is included to capture the difference in quality of relationships facilitated through smaller organizations. Often, a library or museum will have the highest membership or visitor number, potentially orders of magnitude larger than the membership values of churches, for example. While it is understood that larger organizations constitute a larger cross-section of the community, small social organizations more often facilitate bonding social capital. Carpenter (2013) found:

“Although the numbers of networks that community members belonged to and sought help from was not significantly different, the types of networks were. In both cases, faith-based organizations were the most frequently mentioned (23% of networks in low-resilience communities and 21% of networks in high-resilience communities). However, high-resilience communities were networked with local non-profits, schools,
friends, businesses, and municipal organizations in higher numbers. Conversely, low-
resilience communities were networked with state, national or international groups,
military, and federal organizations, as well as family. The different types of
organizations identified by the two groups point to the effectiveness of local networks
of support, including friends and the public and nonprofit sector.”

The 0.25 power counteracts the dwarfing effect in terms of the organization social capital
index that a massive organization like a library would have on a small to medium size
church within the same community, for example. The value of 0.25 was chosen by the
author of this thesis to best achieve the intended results. No data exists as a reference for
the use of another value; this would require extensive pre- and post-disaster data collection
with statistical analysis of hazard event case studies, most likely through the use of these
social capital indices.

Visitor Number is very similar (and includes much of the same rationale) as membership
number. This variable differs in that it accounts for users who are not actively involved,
yet still utilize the organization. An example of this distinction is looking at a library versus
a museum. The two may have similar attendance or usage numbers, but the users of a
library will typically be members, allowing them to rent or check out books. On the other
hand, while museums may offer membership programs, it is more likely that users will not
be a part of the program or will be one-time users. This variable allows for the distinction
to be made between the different visitor types. Visitor number is quantified using the same
equation as membership number, where the value obtained is divided by the largest visitor
number identified, and raised to the 0.25 power, expressed as

\[
\alpha_v = \left( \frac{Visitor \ number \ of \ specific \ organization \ being \ studied}{Maximum \ visitor \ number \ of \ all \ organizations \ being \ studied} \right)^{0.25} \tag{3.1-2}
\]
Note the 0.25 power was chosen similarly as that for Eq. 3.1-1.

Membership and Visitor Change is the general trend of the number of users of the organization.

While this variable could be qualitative (e.g. a percentage or member value), the variable is measured through general trends of increasing, decreasing, or holding constant over time. For a reference time span to measure over, five years is used. An organization that is growing and expanding in number will have more importance to the community and those using it. On the contrary, an organization that has been decreasing in attendance or participation over the past five years is showing a loss of value within the community. Tierney (2014) discussed the social participation and its importance to social capital, as well as a continued and shared vision between its members. If participation grows and progress is being made, the social capital will grow as well; if those two begin to diminish, the ability of the organization will be hindered as well. Hence, a membership trend that is increasing receives a value of 1. For organizations that report a decreasing trend, a value of 0 is assigned. Membership that is constant is assigned a value of 0.5. Membership and visitor change is expressed as

\[ \alpha_{MC} = \begin{cases} 
0 & \text{Decreasing} \\
0.5 & \text{Constant} \\
1.0 & \text{Increasing} 
\end{cases} \] (3.1-3)

Small Group Capability is analyzing whether the organization is set up so that, if desired, members or repeat visitors could join a smaller group or subset of people. A few examples include a church youth group, workout class at a community center, or a book club at a library. In terms of the three types of social capital, joining small groups allows for the individual to move from bridging social capital (built in the membership number variable) into bonding social capital. In a small group, interaction increases and individuals can build
deeper and more meaningful friendships. In the daily operations of a large organization like a library, members do not have a ready-made opportunity to interact. However, with book clubs or other small groups, members are able to associate more closely. Wuthnow (1994) studied small groups, specifically within the church setting. The study showed that participation in small groups stimulated people’s overall involvement in the church, provided help in times of personal crisis, encouraged Bible reading, and built friendships to create a more vibrant church community. Further, Wuthnow (1994) showed that small group members were more likely to have five or more friends in the community than those members not involved in small groups. For measuring the small group variable, the presence of small groups or smaller subsets of people within the organization receives a value of 1. Inability to join such groups counts as 0. Small group capability is expressed as

\[ \alpha_{SG} = \begin{cases} 0 & \text{No} \\ 1 & \text{Yes} \end{cases} \]  

(3.1-4)

Organization Age looks at how long the organization has been a part of the community by looking at the year the organization was founded. An organization with a long-standing presence in the community will be more ingrained within the community, and have a greater importance as compared to a newer organization. When Krishna and Shrader (1999) presented their Social Capital Assessment Tool, the longevity of the organization was included as part of the organizational interviews for social capital assessment. Lochner et al. (1999) used the length of time an individual or family has spent in a particular community as a social capital measure; the same assumption could be made for an organization. If the age of the organization exceeds 25 years, a value of 1 point is assigned. Organizations less than that age receive 0 points. The length of time (25 years) was chosen to represent an approximate length of a generation, so that the organization would affect
two generations of organization members and visitors. Organization age variable is expressed as

\[ \alpha_A = \begin{cases} 0 & \text{Age < 25 years} \\ 1 & \text{Age \geq 25 years} \end{cases} \] (3.1-5)

*Leadership Group* measures the presence of a leadership group to govern the organization. This is not meant to include managers, but rather a group of ownership associates or board members. The group that governs makes decision on organization functions, but also is able to quickly convene and lead in times of disaster or hazard. Aldrich (2011a) found that after a large tsunami, government officials were too busy dealing with widespread damage to look into each community. In one small village, however, a list of needs and damages within the community was compiled by local non-government organization leaders and representatives, then passed along to the government. The MQVN church (Chamlee-Wright and Storr 2009) leadership provided coordination for recovery efforts, as well as reinstating normal church events. Finally, church leadership was also able to advocate for the church members by acting as “an informal bridge between residents and their insurance companies and government relief agencies such as FEMA, SBA, and The Road Home Program” (Chamlee-Wright and Storr, 2009, pg. 447). Presence of a leadership group receives a value of 1, while no leadership group receives 0. Leadership group variable is expressed as

\[ \alpha_{LG} = \begin{cases} 0 & \text{No} \\ 1 & \text{Yes} \end{cases} \] (3.1-6)

*Leadership Style* is meant to capture the depth of the connection between the leadership group and its organization. A group built out of owners, board of investors, or those whose career is financed through the organization will have a direct connection to the organization. In a disaster scenario, helping the organization and people within it will be a central focus. On
the other hand, a leadership group formed out of volunteers or individuals outside the organization will have a lesser connection to the organization. Their main priorities would more likely be focused on their separate careers, with the social organization as an additive piece to their lives or duties. The MQVN church’s pastoral team and lay leadership was entirely focused on fixing the church in order to bring people back and providing as many of the club goods as possible that were available before the storm. In terms of quantification, three values are possible for the leadership style variable. If a leadership group does not exist, this value is automatically 0. If a leadership group does exist but it is only a part-time or volunteered position, the value is also 0. Finally, if a leadership group does exist and it is considered a full-time position, the organization receives 1 point. Leadership style variable is expressed as

\[ \alpha_{LS} = \begin{cases} 
0 & \text{No leadership group} \\
0 & \text{Part-time or volunteer leadership group} \\
1 & \text{Full-time leadership group} 
\end{cases} \]  

(3.1-7)

Regular Events accounts for the frequency of typical or regularly scheduled events. For purposes of this study, this is looked at on a weekly basis. A few examples of these events would be weekly church services, daily education tours a museum, or monthly English-language classes at the library. Reasoning for this variable is two-fold. First, a higher frequency of regular events provides more opportunity for interaction and relationship building between members. Tierney (2014) noted that indicators of social capital are relationship building among groups, high social participation, and overall community engagement. Second, regular events are part of normal life of members or users. These events are part of their daily (or weekly or monthly) routines, and while these events are occurring, there is a general sense of normalcy. The same is true after a disaster;
Butterworth (2005) noted that after the 9/11 attacks, having the Major League Baseball teams return to regularly scheduled games provided a sense of normalcy. One pastor at the time noted that baseball, long called America’s favorite pastime, provided a type of group catharsis or a distraction from the horror of 9/11. The same could be said of church services or library book clubs. While this variable is also quantitative in nature already, it was necessary to convert this into a measure that makes sense within the index. For this variable, if an organization hosts two regular events or less per week, it receives a score of 0. Meeting between three and six times per week results in a 1, and is considered somewhat of an average value. However, if an organization goes “above and beyond” and meets seven or greater times per week, it will receive 2 points. As a note, an event or meeting does not have to include all members to be considered. For example, weekly high school youth groups at a church or book clubs for widows at a library would still be considered a regular event, even though it is just a small subset of the community. Regular events variable is expressed as

\[ \alpha_{ER} = \begin{cases} 
0 & \text{Events } \leq 2 \text{ times per week} \\
1 & \text{3 to 6 events per week} \\
2 & \text{Events } \geq 7 \text{ times per week} 
\end{cases} \]  

(3.1-8)

*Community Events* looks at events run by the organization that are meant to provide outreach into the surrounding neighborhood or city. Examples of this type of event would be a church hosting a food pantry for the homeless in the area or an art festival for local artists hosted by the library. These events can have a positive impact in a number of ways as well. For the people impacted by the event who are not members or regular attendees, it gives them an invitation into the organization, and creates the opportunity for them to become members themselves. Second, interaction will occur between members and non-members,
thereby creating a link between the organization and the surrounding community. Finally, as was the case with regular events, community events also provide members within the organization an opportunity to meet together and interact. The organization becomes more important to the community, especially in the case where the organization is providing a service, like with the example of the food pantry. Again, the MQVN church provides a real-life case study for this variable. Before Hurricane Katrina, the church hosted various events such as farmers markets and Vietnamese cultural events, and had led redevelopment efforts in the area. By establishing themselves within the greater community, they became the central hub of life in the area for both the members and non-members. The same reasoning and scoring structure used in the regular events variable is utilized here. However, because community events are typically less frequent, the measurement range is changed from weekly to monthly. Further, the thresholds are changed to five and ten. In summary, four or less receives 0, between five and nine receives 1, and ten or greater receives 2 points. As a note on the two variables related to events, generalizations or categories were used (rather than a normalization of a specific number of events) due to the way that events vary by month. Also, events are typically spread throughout the organization, so it would be difficult to ensure that all events were accounted for when calculating this variable. Community events variable is expressed as

$$\alpha_{EC} = \begin{cases} 
0 & \text{Events } \leq 4 \text{ times per month} \\
1 & \text{5 to 9 events per month} \\
2 & \text{Events } \geq 10 \text{ times per month}
\end{cases}$$

(P3.1-9)

*Paid Employees* accounts for the number of employees who are paid and rely on the organization for their livelihood, typically looked at as a percentage of total workers. Social capital value is not applied to volunteer workers, as their income comes from other sources.
If an organization has a large number of people dependent on it in terms of income, it becomes more important for the organization to remain within the community. For disaster recovery at the community-level, if an organization is able to retain its employees, those workers will be quicker to remain in the community and be part of the rebuilding process. Rubin et al. (1985) discussed a series of floods in Buchanan County, Virginia between 1957 and 1977. “Despite these experiences, few of the locals have moved away...For many of these people, moving out of the county and away from their jobs and families are unacceptable alternatives” (Rubin et al. 1985, pg. 109). The paid employees variable is calculated as the fraction of total employees that are paid. This number is independent of the total number of employees, as organization with 10 and 1000 employees with half being paid will score the same on this variable. While it could be argued that this aspect is indeed important, it is accounted for through the use of the membership and visitor number variables in the formulation of the final index value. The paid employees variable is expressed as

\[
\alpha_{PE} = \frac{\text{Paid employees}}{\text{Total employees}}
\]  

(3.1-10)

Communication Capability is a measure of how quickly or thoroughly the organization can communicate with their members. Communication allows for greater interaction between the organization and its members, letting them know of different opportunities for interaction. Further, if those methods of communication are shared between members, it opens the door for further interaction between members outside of the organization setting. Communication capability is also important in terms of a post-disaster setting, as a well-connected organization can quickly mobilize to provide aid or relief. Peacock et al. (2010) noted that among other systems, proper communication channels are essential for proper
community functioning. Specifically, part of emergency response includes incident management through coordination of communication. The MQVN church served as “the center stage of communication” (Chamlee-Wright and Storr 2009, pg. 448), where people received information and news, and also acted as a conduit through which relief efforts were organized. An organization with no capability to contact its members will result in a score of 0. An organization with an email list receives 0.5 points, while an email and another method (such as a phone call chain or well-connected social media) receives 1 point. This distinction is made due to the fact that in a post-disaster scenario, access to email may be limited. Having multiple avenues to make contact with someone is more beneficial to the organization. The communication capability variable is expressed as

$$\alpha_{CC} = \begin{cases} 
0 & \text{No communication capabilities} \\
0.5 & \text{Email communication only} \\
1 & \text{Email communication + another form}
\end{cases} \quad (3.1-11)$$

*General Funding* looks at how the organization funds their daily operations and events or pays employee wages. For example, a community pool or recreation center would be funded by the government or tax dollars, while a church is funded through donations of members. In terms of importance of the organization, the organization constructed and funded by the members directly using it would be more important to the users. Brooks (2005) found that charitable giving was included in the Social Capital Community Benchmark Survey from 2000, which looked at participation in and giving to both religious and non-religious organizations. The author concluded that donations both built or enhanced social cohesion, while also making the organizations run more smoothly. Literature also supports the fact that social capital will lead to more charitable giving. So while donation may increase social capital, donations could be used as an indication of the amount of social capital in an organization. While it is understood that funding comes from many different areas,
measurement of this variable looks at three major sources: the government or taxes, organization income, and donations. An organization funded by taxes receives 0, as the people using the organization itself are not actively involved in funding. Organizations funded primarily by donation receive 1 point, as social capital can manifest itself through charitable giving as shown above. Income-based organizations result in a value of 0.5. Here, users are contributing directly, but expect or need something in return, where charitable giving does not. The general funding variable is expressed as

\[
\alpha_F = \begin{cases} 
0 & \text{Government (taxes)} \\
0.5 & \text{Income} \\
1 & \text{Donations}
\end{cases}
\]  

(3.1-12)

*Previous Post-Disaster Experience* asks whether the organization has previously provided aid or relief due to a previous disaster in the community. If the organization has experience, members will be better equipped to serve in the next disaster. The presence of previous post-disaster experience results in a value of 1, while no experience is 0 points. The previous post-disaster experience variable is expressed as

\[
\alpha_{DE} = \begin{cases} 
0 & \text{No} \\
1 & \text{Yes}
\end{cases}
\]  

(3.1-13)

### 3.2. Formulation of Organization Social Capital Index

Now that all variables are defined and quantified, the variables are combined into a single metric, called the organization social capital index (OSCI). All binary variables and the paid employees variable are added together. This includes membership change, small group capability, organization age, leadership group, leadership style, regular events, community events, paid employees, communication capabilities, general funding, and previous post-disaster experience. These variables are all additive; they increase social capital. The maximum value of the final two variables, membership number and visitor number, are applied as a multiplier to the sum of the
previous variables. The maximum of the two variables is used is to ensure that all users of the organization are adequately accounted for while not double-counting any users of the organization. Summarizing, the organization social capital index is calculating the amount of social capital within an organization (summed variables) and weighting that value based on the number of people that the organization affects (weighted multiplier). The OSCI is expressed as

\[
OSCI = max \left( \frac{\alpha_M}{\alpha_V} \right) \cdot \left( \alpha_{MC} + \alpha_{SG} + \alpha_A + \alpha_{LS} + \alpha_{ER} + \alpha_{EC} + \alpha_{PE} + \alpha_C + \alpha_F + \alpha_{DE} \right)
\] (3.2-1)

Where variable definitions are provided in Table 2.

<table>
<thead>
<tr>
<th>ORGANIZATION SOCIAL CAPITAL INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha_M)</td>
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<tr>
<td>(\alpha_V)</td>
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<tr>
<td>(\alpha_{MC})</td>
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<tr>
<td>(\alpha_{SG})</td>
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<td>(\alpha_A)</td>
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<td>(\alpha_C)</td>
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<tr>
<td>(\alpha_F)</td>
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<tr>
<td>(\alpha_{DE})</td>
</tr>
</tbody>
</table>

Table 2: Organization Social Capital Index (OSCI) variable definitions

### 3.3. Building Social Capital Index

Secondly, social capital is formed by the building that houses the social organization. While social capital can be grown through the structure (Carpenter 2013), many of the variables are important in the disaster or post-disaster setting. After a disaster, a building with a high score in the building social capital index will be able to both stay open and perform its regular function, but also act as a place of shelter or relief to people of the community. The building is also a
necessary aid for the organization that typically acts out of the structure. Studies showed that organizations “were most effective in recovery when they had an organizational base, or a physical address in which activities could be centralized and staged” (Carpenter 2013, pg. 27-28). The variables and characteristics for the building social capital index are as follows.

**Building Age** asks when the structure housing the organization was constructed to calculate building age. Typically, a newer building will generally perform better against natural hazards. This reason is two-fold: (1) design requirements and standards and (2) maintenance. First, Sutley and van de Lindt (2016) showed that for wood-frame buildings, newer design codes resulted in less peak inter-story drift under seismic loads. Under the hazard event used in the study, the 1959 design manual models did not provide life safety, the 1978 design method provided life safety at only low intensities, and the current design methods provided excellent performance. The 1971 San Fernando and 1994 Northridge earthquakes were important events which resulted in updated and more stringent code requirements, shown in the results. Secondly, as a general rule, it is assumed a newer building will have less overall “wear and tear” as compared to an older building. It is understood that building age and building performance do not have a direct correlation. However, organization and building characteristics were chosen based on the idea that variables could be attained through short reference interviews with an employee or administrative assistant at the organization. Determining the true anticipated building performance would require a much more in-depth study, whether through reviewing building plans or on-site inspections. Hence, building age was assumed to correlate to building strength and performance. This variable, similar to the membership and visitor number variables, is quantitative in nature but requires normalization to ensure its use in
the building social capital index. To accomplish this, two reference years are chosen, one meant to represent a newer or better designed building, with the other signifying an older building or one designed with outdated codes. A building constructed after the newer reference year will receive 1 point, while a building older than the reference year will receive a score of 0. Anything between is interpolated. The reference years are meant to be chosen by the engineer and are specific to the community being studied. For example, the reference years could be chosen based on maintenance and assumed upkeep, so building ages of 20 and 50 years could be used. The second option for defining reference years is through the use of building code publications, as presented in the variable definition. This study will provide reference years for seismic- and wind-prone hazard areas. For seismic reference years, Sutley and van de Lindt (2016) is recommended. This study observed the difference in performance between structures based on their design codes. The recommendation is to use reference years of 1959 (Blue Book provisions) and 2006 (referred to in the article as modern seismic design provisions). For wind-prone regions, Ghosh (2006), who provided background on the changes in design codes for wind, is recommended. The lower reference year chosen is 1972, when ANSI A58.1-1972 was published. The upper reference year chosen is 1995, when ASCE 7-95 was published, where a series of significant changes were adopted from the previous versions of ASCE 7. In both the seismic and wind case, the references years should be continuously updated so that their assumptions are current. Due to the assumptions made in this thesis to use a seismic event as the hazard scenario, the seismic reference years from Sutley and van de Lindt (2016) are adopted for the index results presented in Chapter 5. The building age variable is expressed as
\[
\beta_A = \begin{cases} 
0 & \text{Building age older than reference year } A \\
-1 & \text{Interpolate between} \\
1 & \text{Building age newer than reference year } B
\end{cases}
\] (3.3-1)

Renovations looks at whether significant renovations had been done to the building, such as large additions or structural renovations; general maintenance is not included. Along with the building age variable, the renovations variable captures the structural quality of the building. Structural renovations are intended to raise the performance of the structure, so any renovations will have a positive effect on building social capital. For additions, any additional construction performed will be required to follow the specified code at the time, and could be designed to a higher overall standard (along with additional reductions in “wear and tear”). As the renovations variable is either a “yes” or “no” answer, its valuation is binary, resulting in a value of 0.1 for renovations completed, or 0 for no renovations. The renovations variable is expressed as

\[
\beta_R = \begin{cases} 
0 & \text{No} \\
0.1 & \text{Yes}
\end{cases}
\] (3.3-2)

Alternative Options looks at if there are any nearby structures that could enable the organization to continue functioning. For example, if a church building were damaged past a functionable level, the church could opt to meet at an undamaged, nearby church or a school gymnasium to continue holding regular events. If the organization is only able to function out of its own structure, the building becomes much more important. For example, it would be unlikely that a museum with a large amount of art or historical pieces would be able to move to another location and properly function in a day-to-day manner. In terms of qualitative measurement, this variable is also binary. However, its value is reversed. If there are no alternative options, the building receives 1 point, due to its increased
importance. If alternative options do exist, the alternative options variable is 0. The alternative options variable is expressed as

\[ \beta_{AL} = \begin{cases} 0 & \text{Yes} \\ 1 & \text{No} \end{cases} \] (3.3-3)

*Community Location* evaluates the location of the organization’s structure with respect to the surrounding neighborhood. If the building is centrally located, it will be more accessible to community members (both those who are part of the organization and those who are not). This is important in typical organization functioning, as a walkable neighborhood encourages interaction and grows social capital, as shown by Glanz (2011). Carpenter (2013) recommends that features which promote community and interaction should be centrally located or dispersed to be available for all residents. Organization location is also important in terms of post-disaster and relief efforts. If the building is located nearby for many of the community members, it is more accessible for those who need to use the building as emergency shelter or receive relief supplies. If an organization is surrounded by homes or other businesses and organizations, the community location variable is scored as 1. For a building that is located out in the country or situated in the midst of an industrial park, for example, the value would be 0. The community locations variable is expressed as

\[ \beta_L = \begin{cases} 0 & \text{Not located near residential area} \\ 1 & \text{Centrally-located} \end{cases} \] (3.3-4)

*Post-Disaster Programs* looks at whether the community or outreach events would be able to continue functioning if the structure were to become unusable. By hosting outreach events that are necessary for groups of people, the building has extra importance within the community. Some examples of these would be hosting a food pantry or English-language classes, where if the building is damaged and these events are no longer offered, those who rely on the events would be negatively affected until the programs returned. This variable
is quantified the same way as alternative options. In the event that the building was
damaged, if the organization’s programs, specifically community or outreach events,
cannot continue, the organization and its structure becomes more important. Hence, a “no”
answer would correspond to a value of 1, while answering “yes” would receive 0 points.
The post-disaster programs variable is expressed as

\[ \beta_{DP} = \begin{cases} 
0 & Yes \\
1 & No 
\end{cases} \] (3.3-5)

*Porch* determines whether the building has a porch or patio attached to or as part of the
building. This refers to the studies of social capital and the built environment by Glanz
(2011) and Carpenter (2013). The presence of a porch provides a built-in opportunity for
interaction between members or a place for hosting community events, which allows for
growth of social capital. Glanz (2011) showed that for a community where 80% of the
homes had a porch (with around 80% of them being used for social activities), there was a
higher sense of satisfaction with number of friends or number of acquaintances. Presence
of a porch would receive a score of 1, and 0 if not. The porch variable is expressed as

\[ \beta_P = \begin{cases} 
0 & No \\
1 & Yes 
\end{cases} \] (3.3-6)

*Sidewalk or Lawn* looks at the presence of a sidewalk or lawn on or nearby the building
premises. This the same effect as the porch variable, though the sidewalk or lawn also
encourages interaction between members and people of the surrounding community.
Carpenter (2013) notes that “chance encounters” are more likely to happen with sidewalks
or lawns present. Further, parks and open spaces could be used to host community events
such as block parties or pickup sports leagues. In post- Hurricane Katrina communities,
these open spaces contributed to a positive living environment after the storm, and also
were used as a distribution point. In interviews by community members, many listed parks
as an important part of the rebuilding process. An organization with a sidewalk or lawn receives 1 point, and receives 0 points if it does not. The sidewalk variable is expressed as

$$\beta_{SL} = \begin{cases} 0 & \text{No} \\ 1 & \text{Yes} \end{cases}$$

(3.3-7)

*Emergency Shelter* is one of the most important of variables in the building social capital index, which asks if the organization has discussed utilizing their structure as an emergency shelter post-disaster. If preparations have been made to utilize the organization’s building as an emergency shelter or a distribution center, the organization will more effectively function for the benefit of the community in the event of a disaster. Proper preparations would include discussions by leadership groups, as well as education for organization members. Examples of these abound in social capital literature, such as Chamlee-Wright and Storr (2009) showing a church serving as both emergency shelter and a distribution center after Hurricane Katrina, Carpenter (2013) noting how faith-based organizations providing aid to the vulnerable, or Johnson (2017) calling for the religious community to be quick to act after natural disasters. Similar to many of the building variables, the emergency shelter is also quantified as a binary value. No emergency shelter preparation results in a 0. However, unlike the other variables, making post-disaster preparations is more heavily weighted and results in a value of 10. Making these preparations is extremely important, and allows the building to be best utilized in a post-disaster setting. When combining variables into a single index, reasoning for the larger value will be clearer. The emergency shelter variable is expressed as

$$\beta_{ES} = \begin{cases} 0 & \text{No} \\ 10 & \text{Yes} \end{cases}$$

(3.3-8a)

*Distribution Center* is a modification to the emergency shelter variable and can be used in the event that the building is no longer functionable. Further discussion of this variable is
discussed in Section 3.6. This variable accounts for whether preparations had been made for utilizing the space or land for distribution of resources such as blankets, food, or clothing. Compared to emergency shelter preparation, this is not as impactful, but any preparation for post-disaster relief would be helpful to community members. This variable is quantified similar to the emergency shelter variable, but receives a score of either 0 or 4.

The distribution center variable is expressed as

$$
\beta_{DC} = \begin{cases} 
0 & No \\
4 & Yes 
\end{cases}
$$

\[ (3.3-8b) \]

*Kitchen* asks if the building has a kitchen. This variable, along with the next five variables, look at the organization’s capability to serve as an emergency shelter, if required. A kitchen is required to prepare food for those living within the shelter. Additionally, the kitchen could be used to prepare food to distribute to community members, especially the socially vulnerable (Carpenter 2013). The MQVN church (Chamlee-Wright and Storr 2009) acted as the site where people could find necessities such as food. Having a kitchen will result in 1 point, with 0 points for it not being included. The same is true of the final five variables, where having the characteristic will result in 1 point, with 0 points for it not being present.

The kitchen variable is expressed as

$$
\beta_K = \begin{cases} 
0 & No \\
1 & Yes 
\end{cases}
$$

\[ (3.3-9) \]

*Large, Multipurpose Room* determines whether a large-multipurpose room is present. In a post-disaster or emergency setting, this is needed for space to house people or materials. A large gym or classroom can serve as a place to stay for community members who have been displaced from their home. The multipurpose room variable is expressed as

$$
\beta_{LR} = \begin{cases} 
0 & No \\
1 & Yes 
\end{cases}
$$

\[ (3.3-10) \]
Small Rooms looks at whether there are small rooms in the building, such as offices or classrooms. The presence of these small rooms or offices allows for people to be housed after a disaster, but also to provide separate places or privacy for some of the residents, such as nursing mothers. Felix et al. (2013) noted how family homes give protection, comfort, and privacy. If more of these benefits can be provided in post-disaster shelters, it will make occupants feel more at home, feel more comfortable with their living situation, and begin the restoration and rebuilding process. The small rooms variable is expressed as

\[ \beta_{SR} = \begin{cases} 0 & \text{No} \\ 1 & \text{Yes} \end{cases} \]  

(3.3-11)

Storage Area analyzes whether a storage shed or location is present within or near to the structure. A storage area would greatly increase the organization’s ability to house people after a disaster or distribute goods. The storage area could hold the belongings of those who are displaced from their homes, important items in relief like blankets or hygiene products, or extra food. The storage area variable is expressed as

\[ \beta_{ST} = \begin{cases} 0 & \text{No} \\ 1 & \text{Yes} \end{cases} \]  

(3.3-12)

Bathrooms with Showers looks at whether a bathroom with showers exists in the building. Having this amenity allows the organization to more effectively serve as an emergency shelter. A shower and place to clean will make the emergency shelter more comfortable or home-like. The bathrooms with showers variable is expressed as

\[ \beta_{BR} = \begin{cases} 0 & \text{No} \\ 1 & \text{Yes} \end{cases} \]  

(3.3-13)

Backup Generator evaluates whether a backup generator is present. Having a backup generator will allow a building to maintain power in a post-disaster setting, while many of the nearby buildings may not have power. The backup generator variable is expressed as
\[ \beta_G = \begin{cases} 0 & \text{No} \\ 1 & \text{Yes} \end{cases} \quad (3.3-14) \]

3.4. Formulation of Building Social Capital Index

The combination of variables into a single index for the building social capital index is slightly more intensive than the organization social capital index. First, the six variables regarding building characteristics (kitchen, multipurpose room, small rooms, storage area, bathroom with showers, and backup generator) are summed. Second, the maximum of this sum or the emergency shelter variable is taken. This is due to the fact that if preparations are in place for the building to serve as an emergency shelter, the organization itself is more prepared and the building is better equipped to perform, hence the emergency shelter variable being more heavily weighted. The points are not double-counted, as it is assumed that a building with emergency shelter preparations made will have many of the building components already. Third, the maximum value is added to the renovations, alternative options, post-disaster programs, and porch variable. Next, this sum is taken and multiplied by the minimum of one or the sum of the building age and renovations variables, to account for building strength. For example, if a building is old or poorly maintained and a large disaster comes along, even if preparations have been made and the building exhibits social capital, it will not be as likely to manifest its importance as it will be less like to withstand the disaster. However, a newly designed building with modern codes will be more likely to stand up to the disaster, and its importance will be felt. Finally, the community location and sidewalk or lawn variable are added onto the final number, as they are independent of the structure. These variables benefit social capital through interaction during regular organization functioning, and would still be important for use as a distribution center. With the BSCI is expressed as

\[ BSCI = \min(\beta_A + \beta_R) \cdot (\beta_{AL} + \beta_{DP} + \beta_P + \max(\beta_{K} + \beta_{LR} + \beta_{SR} + \beta_{ST} + \beta_{BR} + \beta_{ST})) + \beta_L + \beta_{SL} \quad (3.4-1) \]

Where the variable definitions are provided in Table 3.
### BUILDING SOCIAL CAPITAL INDEX

<table>
<thead>
<tr>
<th>β</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_A</td>
<td>Building age</td>
</tr>
<tr>
<td>B_R</td>
<td>Renovations</td>
</tr>
<tr>
<td>B_AL</td>
<td>Alternative options</td>
</tr>
<tr>
<td>B_DP</td>
<td>Post-disaster programs</td>
</tr>
<tr>
<td>B_P</td>
<td>Porch</td>
</tr>
<tr>
<td>B_ES</td>
<td>Emergency shelter</td>
</tr>
<tr>
<td>B_DC</td>
<td>Distribution center (modified from emergency shelter)</td>
</tr>
<tr>
<td>B_K</td>
<td>Kitchen</td>
</tr>
<tr>
<td>B_LR</td>
<td>Large, multipurpose room</td>
</tr>
<tr>
<td>B_SR</td>
<td>Small rooms</td>
</tr>
<tr>
<td>B_ST</td>
<td>Storage area</td>
</tr>
<tr>
<td>B_BR</td>
<td>Bathrooms with showers</td>
</tr>
<tr>
<td>B_G</td>
<td>Backup generator</td>
</tr>
<tr>
<td>B_L</td>
<td>Community location</td>
</tr>
<tr>
<td>B_SL</td>
<td>Sidewalk or lawn</td>
</tr>
</tbody>
</table>

*Table 3: Building Social Capital Index (BSCI) variable definitions*

### 3.5 Critical Infrastructure Interdependency Index

The final index developed in this study is the critical infrastructure interdependency index. The Department of Homeland Security identifies 16 categories of critical infrastructure. These critical infrastructures are defined as those “assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof” (Department of Homeland Security 2017). ASCE 7 defines critical infrastructure as essential facilities, with examples being hospitals, power plants, government buildings, emergency response structures, or storm shelters. Each of these critical infrastructures require other infrastructure to remain operational over an extended period of time. According to Rinaldi et al. (2001), there are four types of interdependencies, namely, physical, cyber, geographical, and logical. Physical interdependencies have been studied the most extensively, and
include a physical output from one system to another. For example, a hospital requires a power supply to remain function. Physical interdependencies are accounted for in ASCE 7, where Risk Category IV includes essential facilities (i.e. critical infrastructure), but also includes buildings “required to maintain the functionality of other Risk Category IV structures” as part of Risk Category IV importance (ASCE 7-16, pg. 2).

Two infrastructures are geographically interdependent if they are located near each other, where a disruption of the nearby structure would cause a disruption at the other as well. Geographic interdependencies are included in the critical infrastructure interdependency index. Due to the nature of cyber interdependencies typically not relating directly to a structure, cyber interdependencies are not included in the index. The final type of interdependency is logical interdependencies, which is defined as all interdependencies are not included in the first three categories. An example of a logical interdependency provided by Rinaldi et al. (2001) was between the petroleum and transportation infrastructures, where a lowering of gas prices may lead to increased travel on highways, which creates higher amounts of traffic on the roads. An example is relevant to the post-disaster setting would be the residential sector and hospitals. While this interdependency is not as critical as power and water supply in the immediate aftermath of a disaster (i.e. a physical interdependency), it becomes increasingly important as recovery progresses due to the fact that medical staff will need a place to live as they begin to recover themselves. If the community shows little promise that the residential sector will be improved or repaired quickly, this may reduce the staff that is able to work at the hospital. In terms of this study, this type of interdependency is the most relevant, as this will be where most social organizations (as well as most typical community buildings) will fall.
There are many complex interdependency models in the literature that use simulation and system flow diagrams. However, in being consistent with the method of data collection used for the first two indices, a more straightforward method of calculation was used. To compute the critical infrastructure interdependency index, the number of interdependencies between the study structure and all critical infrastructure are summed. Further, the equation also weights the importance of the different type of interdependency that the study structure is providing. To emphasize, this index only captures interdependencies with critical infrastructure as identified by the ASCE 7 risk category IV (not necessarily aligning with the DHS 16 critical infrastructures). The CIII is expressed as

$$CIII = w_P \cdot \sum \gamma_{Pi} + w_L \cdot \sum \gamma_{Li} + w_G \cdot \sum \gamma_{Gi}$$  \hspace{1cm} (3.5-1)

where $\gamma_{Pi}$, $\gamma_{Li}$, and $\gamma_{Gi}$ represent the physical, logical, and geographic interdependencies that a single social infrastructure has with all critical infrastructure within a community, respectively. Each type of interdependency was also assigned a weight, where the weight of interdependency type is represented by $w_P$, $w_L$, and $w_G$ for physical, logical and geographic. Assigning the physical interdependency weight, $w_P$, a value of two is done to highlight the importance of these interdependencies in the immediate post-disaster setting. A hospital without power due to failure of a power plant will result in the hospital being unable to provide service to the community. Logical interdependencies, on the other hand, are more important in the long-term, community rebuilding stage. Geographic interdependencies are important for reducing nearby damage, but this can be worked around in the immediate disaster sense. Hence, logical ($w_L$) and geographic ($w_G$) weight variables are both assigned a value of one.

Using this index as a measure acknowledges the importance of essential facilities to the recovery of a community. It also measures the additional importance of social infrastructures
along with other typical community buildings) in terms of how they indirectly aid post-disaster recovery through interdependencies with essential facilities.

3.6 Variations in Index Measures Under Different Hazard Scenarios

From the variable definitions in earlier sections, it is clear that the relative importance, or even manifestation, of certain variables in the indices are dependent on the functioning status of the organization or community. For example, the emergency shelter variable in the building social capital index is only important when a hazard is either imminent or has occurred and the building remained functional. The next step of the social capital model from Figure 3 is to revisit the variables in the social capital indices through the lens of a hazard scenario. Equations 3.2-1 and 3.4-1 are altered based on three different phases along the hazard scenario timeline: (1) pre-disaster conditions, (2) the hazard event, and (3) recovery. These three phases studied match the three steps of community resilience from the resilience framework shown in Figure 2. A seismic event is the hazard being considered here. It is understood that a true community-level hazard scenario would result in different accelerations felt for locations within the community, and consequently different structures. For simplification, however, it is assumed in this study that all buildings within the community will experience the same acceleration. Further, a code-level hazard scenario is studied here. Therefore, it is assumed that the only buildings that remain functional are critical infrastructure such as hospitals and power plants.

While the organization and building social capital indices change based on the hazard scenario, the critical infrastructure interdependency index does not change between phases. The interdependencies still exist and the infrastructure are continually dependent on each other. Hence, for the critical infrastructure interdependency, Equation 3.5-1 is used through each phase of the hazard scenario.
Pre-Disaster Conditions coincides with normal or typical daily functioning of the organization and community. For the organization social capital index under pre-disaster conditions, the index is capturing the importance of the organization to community members through variables like membership number and paid employees. It also measures the amount of bridging social capital built through the organization through the small groups and regular events variables, which also provide opportunities for members and frequent users to grow bonding social capital. Three variables, leadership group, leadership group style, and post-disaster experience, are omitted in the pre-disaster phase, as they are more impactful in a disaster, rather than the typical setting. As discussed in the variable definitions, the true value of the two leadership variables are in the hazard scenario. Activation of the post-disaster experience variable is only necessary if a disaster occurs. The new equation for organization social capital is expressed as

$$OSC1 = \max \left( \frac{\alpha_M}{\alpha_Y} \right) \cdot (\alpha_{MC} + \alpha_{SG} + \alpha_A + \alpha_{ER} + \alpha_{EC} + \alpha_{PE} + \alpha_C + \alpha_P) \quad (3.6-1)$$

For the building social capital index, the index captures the importance of the structure to both the organization itself, as well as those who live near the organization. Hence, all variables are included in this hazard phase. The buildings with the highest building social capital in the no hazard scenario represent those buildings which are the most impactful to a community. In this case, they also represent those structures which would have the largest negative impact if they were to be lost or damaged. The equation for the building social capital index in the pre-disaster conditions would be the same as that provided initially (Equation 3.4-1).

Hazard Event looks at the immediate response of an organization or community after a hazard event. This would correspond to the community functionality drop (step 2) shown in Figure
2. As a reminder, that drop corresponds to a code-level seismic event, causing loss of functionality in all structures except for critical infrastructure. For the organization social capital index, the index captures the organization’s capacity to perform disaster action. Literature shows that this is directly tied to the amount of social capital that had been grown in the pre-disaster setting, where “communities with high levels of social capital were efficient in rescue, relief and recovery” (Chamlee-Wright and Storr 2011, pg. 269). Because of this, all organization social capital variables are included in the hazard event phase, and the equation used is identical to Equation 3.2-1. As mentioned above, the only buildings that remain functional are critical infrastructures, so it is assumed that social organization structures have either lost all functionality or collapsed. The building does have some importance in terms of building social capital however. As mentioned in the emergency shelter variable definition, if preparations to use the building and its location as a distribution center have been made; this still impacts the capital of the building. Hence, even though the building has collapsed, the distribution center variable (i.e. modified emergency shelter variable) is included. Community location and sidewalk or lawn are still included as they are related to the building’s capacity to act as a distribution center. If the building is in a central location, it will be accessible to more community members, and the sidewalk or lawn gives the organization a location for material distribution. The BSCI during the hazard event phase is expressed as

\[
BSCI = \beta_{DC} + \beta_{L} + \beta_{SL}
\]  

(3.6-2)

Recovery. The final step along the disaster timeline is the recovery phase. While the timing of this will vary by each community, the weeks or months following the disaster event is assumed for the index equations developed here. For the organization social capital index, the interconnectedness of the organization and its members it no longer important due to
the fact that the building is no longer functioning. Regular events are no longer occurring and paid employees have no job to return to for the time. Carpenter (2013) notes that a community without “infrastructure that supports social networks, communities are at a practical as well as spiritual disadvantage.” The surrounding community is hurt by the lack of social capital from the organization. Additionally, social capital is no longer being grown, as the events which grew social capital in the first place are not taking place. However, the organization may still be able to perform disaster relief efforts on a limited basis, so some variables are still included. The leadership group which mobilizes the organization in those relief efforts, and their communication with the members are important, so those variables are included. Any post-disaster experience is still beneficial. Finally, the community events variable is also included, as relief and outreach efforts would be considered events for members to attend and be involved with. The OSCI during the recovery phase is expressed as

\[
OSCI = \max \left( \frac{\alpha_M}{\alpha_Y} \right) \cdot (\alpha_{LG} + \alpha_{LS} + \alpha_{EC} + \alpha_C + \alpha_{DE})
\]  

(3.6-3)

Similar to the organization social capital index during the recovery phase, the building social capital index only accounts for the relief efforts that are being put forth by the organization through their building. Assuming that relief efforts continue to occur, the building social capital at the recovery phase would be identical to the building social capital at the hazard event phase. This makes sense, as the structure is not functioning in both phases and its importance relies solely on its ability to serve in the post-disaster setting. Hence, the equation for the building social capital index used in the recovery phase is identical to the one used in the hazard event phase (Equation 3.6-2).
While the hazard scenario (and its corresponding phases) laid out in this situation assumes the structure is no longer functioning, designing the building to higher standards allows for the social capital to be improved. The impacts of this practice are studied in the next chapter.
Chapter 4: Cross-Laminated Timber (CLT) Design

The first motivation of this study, as laid out in Chapter 2, was to provide a quantitative method for measuring the social capital that is inherent within a social organization. A second motivation of the study was to demonstrate the importance of these social organizations, so that the organization’s importance will be translated to improved design in the pre-disaster setting and better utilization of these structures in post-disaster reconstruction efforts. Advocating for improved design would lead to better performance of structures under hazards, improved social capital in the community, and therefore better and faster community recovery.

As an example of how improved design could manifest itself, this study provides a design example of a two-story cross-laminated timber (CLT) building representing a typical church. As CLT is still a fairly new material, this work makes strides in the area of CLT research by showing the methodology used for design and demonstrating how CLTs can be used to achieve higher seismic performance. This example demonstrates how CLTs can be used as an alternative construction system to steel and concrete. As this building is designed to strict, high-performance standards, carried by a new material in CLT panels, this two-story church will add a specific archetype to the building database in the broader literature.

This chapter outlines the literature review performed on CLT structures and performance-based wood design, goes through the design process, presents the design results of the church building, and exemplifies the building performance under seismic loads from modeling software.

4.1. CLT Literature Review

Because CLT is still a fairly new material, there is a great deal of research being done on CLT panels. The “CLT Handbook: U.S. Edition” by Karacabeyli and Douglas (published in 2013) and the “Standard for Performance-Rated Cross-Laminated Timber” by The Engineered Wood
Association (APA), published in 2012, provides background information on CLT. Specifically, they discuss what CLT panels are, their use, their construction, and much more.

The “CLT Handbook: U.S. Edition” from Karacabeyli and Douglas in 2013, is a 12-chapter document that gives background on CLT panels. Cross-laminated timber is usually formed in panels with maximum dimensions of 60 feet long, ten feet wide, and 20 inches thick. These panels are constructed by laying layers of individual boards (ranging from 5/8 to 2 inches thick, with 1-3/8 inch being most common) orthogonal to each other, typically in an odd-numbered amount of layers. A five-layer panel, for example, would have the first, third, and fifth layers parallel to each other, with the second and fourth layer being perpendicular to the others. A schematic is provided in Figure 4. CLT panels are typically used in wall or roof-floor applications because of their high dimensional stability. They exhibit high in-plane and out-of-plane bending and shear stiffness, and are effective in resisting lateral forces, specifically seismic forces. The “CLT Handbook” discusses other topics such as structural design, lateral resistance, manufacturing processes, fire performance, connection requirements and more.

The CLT standard published by the APA (2012) discussed similar introductory items to CLT panels, but also provided component requirements, performance criteria, and design properties. Component requirements specify lumber grade, moisture content, and internal joint material minimums. Almost any species is allowed in CLT panels, but each layer is required to be made of the same species; adjacent layers can differ by species. The performance criteria provided minimum strength characteristics for bending, elastic modulus, tension, compression, parallel
shear, and perpendicular shear. Minimum values are provided for the panel’s major and minor strength directions. The major strength direction is the direction parallel to the outer layers, and the minor strength is the direction perpendicular to that. Finally, the APA (2012) provides allowable design properties for the same strength variables mentioned above. The minimum strength characteristics and allowable design values are provided for seven different panel grades, depending on the type of lumber combinations used.

Because of its high strength against lateral loads, much of the research is focused on CLT performance under lateral and cyclic loading. One of the first North American tests completed was Popovski et al. (2010) on the lateral load resistance of CLT panels. To do this, 32 CLT panel configurations were tested. Different configurations consisted of changing connector numbers and types, panel aspect ratios, number of panels (utilizing a step joint), and the influence of openings. Under testing, the walls acted as rigid bodies; some shear deformation was noticed, but it was negligible compared to the deformation in the connectors and hold-downs. Tests from wall sections utilizing step joints lowered stiffness, providing better deformation performance. Panel aspect ratio also changed the total load that could be carried. A wall longer than the 1:1 aspect ratio carried more lateral force, while a wall taller than the 1:1 ratio had similar lateral force-carrying capacity to the 1:1 aspect ratio walls. However, the use of a single two-story wall performed much better than two individual walls stacked above each other. Finally, including hold-downs on wall panel ends with brackets improved seismic performance.

As researchers proved that CLT panels perform well under seismic loading, more research began to integrate CLT construction into the typical building market. In order to do this, however, a better understanding of seismic behavior was needed. Pei et al. (2013) attempted to do this through the development of the response-modification factor (R-factor) for CLT panels. The R-
factor is used in typical seismic design codes in the United States. The authors began by developing an equation to calculate the lateral resistance of CLT panels based on the load-slip resistance of the connectors and the panel geometry. Lateral resistance of a wall (a series of panels) was calculated as the summation of the individual panels. To obtain the load-slip resistance of the connectors, the authors used a ten-parameter hysteretic model shown in Figure 5. The connectors tested included a varying number of brackets, three different screw types, and the optional use of hold-downs. Once hysteretic parameters were obtained, tables providing the allowable lateral design capacity of CLT panels were developed. These panels varied by number of brackets and the aspect ratio of the wall, and were performed for each of the three screw types. Once completed, a six-story apartment building was designed using CLT panels and analyzed through nonlinear time history analyses in SAPWood. Based on these results, Pei et al. (2013) recommended the use of an R-factor between 3.5 and 5.5.

Schneider et al. (2014) quantified the damage in connections for CLT panels under cyclic loading. Typically, CLT wall failure will occur through fastener yielding or pullout of the fasteners from the panel. The authors performed a series of tests in the parallel and perpendicular direction to compute a damage index through loading. Results varied by the panel loading direction and the type of screw used. For example, the failure mode for the parallel to grain tests was pullout of the connectors. If self-drilling screws were used, it was more likely to see the head of the fastener
sheared off. In the perpendicular loading case, crushing of the wood was experienced in the top layer of the panel. The authors noted that the failure in the perpendicular direction was more severe than that parallel to the grain, because of the ductility experienced when fasteners pullout. For each of the test setups, a damage index was calculated. Five of the six connection types experienced a damage index of greater than 0.8, which was deemed failure. Schneider et al. (2014) also provided damage index values for five damage states: none, minor, moderate, severe, and collapse.

While research had been completed on lateral load resistance and successful tests had been performed, a good understanding of the cyclic behavior of CLT walls and their connections was not available. Gavric et al. (2015) attempted to understand the behavior of CLT walls through identifying energy dissipation properties, identifying failure modes, and performing various analytical studies. Gavric et al. (2015) referred to a previous study where CLT behavior was classified as either later deformation or the interaction of adjacent walls. Lateral deformation came from four components, namely rocking, sliding, shear, and bending. For the other classification, adjacent walls could perform as individual panels, partially fixed with a semi-rigid connection, or as a single wall with a fixed connection. Test results showed that the behavior is still largely dependent on the connection, specifically on the number of fasteners. In terms of displacement, rocking and sliding were the predominant deformation mechanisms, with shear and bending accounting for only 3%. Cyclically, the CLT panels performed very well. A wall that experiences a mostly rocking behavior will return to its starting position without considerable residual displacement, with the only damage localized to the connection area. Tests showed that for CLT construction, damage can be quickly and easily replaced, allowing for the building to achieve a rapid return to functionality. The same is not true when the wall experiences a sliding motion, however. When sliding, the fasteners begin to pull out, which leads to an overall reduction in
strength and stiffness. Equations to perform pushover analyses of different wall systems were developed and verified by experimental results.

Popovski and Gavric (2016) tested the performance of a full scale two-story CLT house, testing the strength, deformation capacity, and global behavior of the structure. When tested to failure (80% load drop), the average shear resistance was 3.4 times greater than the design shear value. The house was tested in both the north-south and east-west directions, and achieved similar strength in each direction. However, the north-south results showed more displacement due to the loss in stiffness from the door opening and the reduced aspect ratio. This loss in stiffness did not result in any torsional effects. Importantly, once the deformation limit was reached, the wall panels and floors were mostly undamaged, except for at or near the connections. The authors did not detect any global instabilities. Failure was typically experienced when the first-story brackets exceeded their shear capacity, along with some fastener yielding and wood crushing in the step joints. The hold-downs and the CLT panels themselves experienced very little damage throughout the entire loading process. Finally, the building achieved maximum interstory drift of 3.2%, but primarily through sliding behavior, which is less ideal than rocking. If more connections or fasteners had been used, the story drift may have changed.

Pei et al. (2016) provide a summary of the progress and challenges in CLT for seismic regions. CLT testing was initially centralized in European countries such as Slovenia, Macedonia, Italy, and others. Tests showed that lateral load resistance was dependent primarily upon anchorage strength and local connection failure. A later studied showed that a CLT panel’s shear strength was highly dependent on the boundary conditions. Further, when testing openings in shear walls, studies found that openings up to 30% of the wall area did not affect the shear strength of the wall. Shake-table tests showed that “CLT panels acted almost as rigid bodies during dynamic
excitation,” (Pei et al. 2016, pg. 2) while the connections provided ductility. Italian tests furthered these findings, and noted that nearly all shear deformation came from the connections, rather than from the panel itself. Another test noted that the panels in both the floors and walls would remain elastic, so the author suggested CLT panels as a good candidate for use in performance-based seismic design (PBSD). Specifically, the author used the term “No Damage Design” (NDD), a special case of PBSD. While this may be true, shake-table tests in Italy showed that for large earthquake events, the building may experience significant damage in the connections and high accelerations in upper floors. Tests reached into North America, and in 2012 one article attempted to find seismic modification factors for CLT panels. This work was utilized in Karacabeyli and Douglas (2013) mentioned above, allowing for designers to begin utilizing CLT in North American construction projects. Another study suggested a response modification coefficient, or R-factor, of 4.5 for use with ASCE-7 in the United States. Overall, buildings constructed from CLT panels have performed well, and proponents of CLT construction are pushing for CLT to take a share of the market in mid-level building projects. In order to do this, however, research needs to be continually done in terms of CLT as a lateral force-resisting system and under performance-based design. In reference to performance-based design, the authors proposed a three-tiered performance expectation for CLT buildings. This provides system performance and structural component damage for four different earthquake levels, at three different design tiers, code minimum, code plus, and resilience.

After reviewing the literature related to CLT panels, it was clear that this is not only a viable option for buildings designed to achieve code-level performance providing life safety, but also an option for achieving higher levels of performance, such as immediate occupancy. Hence,
performance-based design was chosen as the design philosophy, and the simplified direct displacement design was selected as the design methodology for the two-story church.

4.2. Performance-Based Seismic Design

Before 2002, advancements had been made in performance-based design, but had not yet been applied to timber structures. Filiatrault and Folz (2002) took the previous growth of performance-based design and applied it to wood structures, which was especially important to the engineering community, due to the fact that wood buildings constitute a large percentage of buildings in the United States, and damage to wood buildings typically comes from lateral deformation. Further, wood-frame structures typically exhibit an inelastic response under lateral deformation, and R-factors for wood are difficult to justify or assign. Therefore, the current force-based procedure may not be the best design methodology for wood-frame structures. Because of this, the authors developed a displacement-based design procedure for wood-frame buildings. First, designers select a target displacement at a specific hazard event. Next, a structural system is selected, and in this study the authors used wood shear wall assemblies. The next two steps require calculations for the equivalent viscous damping and equivalent elastic period, both referring to the initial target displacement. Step five is to calculate the required stiffness of our single-degree of freedom model, while step six is to calculate the actual lateral stiffness based on pushover analyses. The process becomes iterative by comparing the results from five and six; if values have a large difference, the designer should return to step two. Finally, once the stiffnesses are similar, the base shear can be calculated and lateral resistance members can be selected. The authors finish the study by performing a design example of a 2.4m by 2.4m shear wall, and validated the methodology by running nonlinear time history analyses.
One specific example of performance-based timber engineering is the NEES-Wood project. Pang et al. (2010) gives an overview of this NEES-Wood project, which is working to develop a performance-based design procedure for timber buildings, specifically for use in seismic regions. Initially, part of that test was developing a displacement-controlled design behavior based on full-scale testing of a two-story structure. This procedure was previously published in 2009 (Pang and Rosowsky 2009). Similar to that of Filiatrault and Folz (2002), the method attempts to limit the deflections of wood structures, as much of the structural issues that arise are displacement related. In this article, the authors lay out a simplified version of the direct-displacement design (SDDD). The simplified method has two benefits over the original method, in that it can be done with the use of a spreadsheet and that probabilities of non-exceedance other than 50% can be used for performance levels. The non-exceedance probabilities other than the median value of 50% are accounted for with a $C_{NE}$ factor, which is calculated in the first step and modifies the design spectral acceleration. To do this, they go through the method for a six-story building design. Performance objectives were specified for four different levels of earthquake intensity, with a corresponding interstory drift limit (the relative displacement between two stories) and probability of non-exceedance. Performance levels one through three correspond to immediate occupancy, life safety, and collapse prevention, respectively. The ten-step process is not iterative, as it was in Filiatrault and Folz (2002). Once the story shears are calculated based on drift and non-exceedance probabilities, shear walls are selected to carry the story force. Finally, to verify that the design methodology was sufficient, nonlinear time history analyses were performed on the six-story structure. The methodology described in Pang et al. (2010) was adopted here to design the two-story church building.
4.3. Design Process & Methods

One of the motivations of this study was to advocate for the importance of social organization structures, leading to improved performance and design. The performance objective for the church building was chosen to be immediate occupancy for a maximum considered earthquake. High structural performance will lead to higher scores in the social capital indices, as this building will be able to remain functional even during the harshest of hazard events (seismic in this thesis). Building layouts were obtained from Church Development Services, LLC, a company that provides building plans and other consulting services to religious organizations. Some floor plans are available online. The first (Figure 6) and second (Figure 7) story floor plans for the church chosen are provided. This church was chosen for a few reasons. First, the structure is rectangular, allowing for a simpler design process. Additionally, the church building included many of the variables used in the building social capital index. For example, the large room on the left side of the building could serve as an emergency shelter (Chamlee-Wright and Storr 2009).
Figure 6: Two-story church building first floor layout and dimensions
Figure 7: Two-story church building second floor layout and dimensions
The first step in the SDDD procedure is choosing the performance expectations, such as drift limits and hazard probability of non-exceedance. For this project, an 80% probability of non-exceedance was used for the seismic hazard. This will capture a larger amount of the earthquake events that occur, and will increase the overall base shear designed for. In the case of the CLT church structure, increasing probabilities from 50% to 80% nearly doubled the design base shear. Using a non-exceedance probability other than 50% requires the calculation of a $C_{NE}$ factor, which is used to amplify the spectral acceleration. Part of the calculation of the $C_{NE}$ factor is the logarithmic standard deviation. Using an assumed ground motion uncertainty of 0.4 and measurement uncertainty of 0.6, both consistent with the Pang et al. (2010) article, led to a logarithmic standard deviation of 0.75.

The next step was to choose drift limits. As mentioned above, it was required to have the church remain functional during a maximum considered earthquake (MCE). The Level 1 performance objective specified in Pang et al. (2010) uses a performance expectation of 1% of interstory drift. This drift limit corresponds to immediate occupancy, as was selected as the performance objective in this study. The church building was assumed to be located in San Francisco, California, with an MCE with site class D used as the seismic hazard. Further, to reemphasize the criticality of these buildings, the coefficients were taken as Risk Category IV, which is typically specified for critical infrastructure. Spectral accelerations were found to be 1.5g and 0.957g, as given by the USGS Design Maps (which are based on ASCE 7-10 seismic hazard levels (Appendix A). Another variable requiring assumptions was the damping reduction factor; assumptions used in the Pang et al. (2010) building were chosen for the church design as well (intrinsic damping of 5% and stiffness ratios of 0.3). Following the rest of the procedure resulted in a base shear of 716.6kips, with story shears of 716.6kips and 552.9kips on the 1st and 2nd stories,
respectively. The *Microsoft Excel* spreadsheet used to calculate these values is provided in Appendix B, along with detailed calculations for story weights. The shaded cells represent user inputs, while the rest of the cells are calculated.

While a great deal of research has been done in the lateral performance of CLT panels, a codified approach for selecting and designing CLT panels does not exist. However, the “CLT Handbook” published by Karacabeyli and Douglas (2013) does provide the load capacity of certain CLT panel layouts. The handbook developed a numerical model for calculating the resistance of CLT wall panels based on the study from Popovski (2010). Once it was determined that the test results and the model matched, the authors calculated the 10 hysteretic parameters (see Figure 5) for seven different connectors: a hold-down, three screw types, and the same three screw types including a half-lapped joint. Once hysteretic parameters were determined, the authors determined a capacity for nine different bracket layouts, shown in Figure 8. This was repeated for each of the three screw types. It is assumed that two hold-downs are present in each of the layouts. Through this, three tables were developed (for each screw type); an example of these tables (for the 16D-SN screws) is shown in Figure 9.
Figure 8: CLT wall panel bracket layout from Karacabeyli and Douglas (2013)

![Bracket layout diagram]

Figure 9: CLT wall panel load tables developed by Karacabeyli and Douglas (2013)

<table>
<thead>
<tr>
<th>Fastener Type: 16D-SN</th>
<th>Wall Length (ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single-panel Wall</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>No. of Brackets²</td>
<td>Bracket Installation</td>
</tr>
<tr>
<td>2</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>DE</td>
</tr>
<tr>
<td></td>
<td>DA</td>
</tr>
<tr>
<td>3</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>DE</td>
</tr>
<tr>
<td></td>
<td>DA</td>
</tr>
<tr>
<td>4</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>DE</td>
</tr>
<tr>
<td></td>
<td>DA</td>
</tr>
</tbody>
</table>
There are a few items to make note of here. First off, it can be seen that these tables are independent of panel thickness. As the literature from Section 4.1 showed, a CLT panel will remain relatively intact in the case of lateral loading, so lateral load resistance is based primarily upon connection. Panel thickness and grades were selected based on the gravity loading. Additionally, when using the LRFD design methodology, load capacities listed in the table allow for multiplication by a factor of 1.6. Third, all wall panels tested for creating the table were eight feet tall. Since no data was available relating to 11 feet tall walls (i.e. the height of the wall panels assumed in the church example), it was assumed that using similar wall aspect ratios would lead to the most similar and consistent results. For example, a wall with 6’ x 8’ dimensions was deemed to have the same strength as a 9’ x 12’ wall.

For selecting which walls would carry lateral load, it was assumed that the exterior walls, plus the central interior wall (running north-south) would be used initially. Other walls could be added if needed. Hence, in the north-south (N-S) direction, the total load would be carried by three lines of 110.5 feet. The east-west (E-W) direction would be carried by two lines of 161 feet. Broken down into a number of full, nine-foot-long panels, this resulted in 36 panels in either direction (18 per line N-S, and 12 per line E-W). This meant each of the directions could be designed with the same layout and panel dimensions, without losing overall efficiency of the panels.

SFS2 screws were chosen as the typical bracket connector. For the four double all (DA) brackets, the capacity from the tables provided was 12.6kips per full wall panel. This represented the maximum strength layout provided in the tables. However, this bracket layout was insufficient in both the N-S and E-W directions, and more walls needed to be utilized. The CLT panel layout for the first floor is shown in Figure 10 below, with CLT panels depicted by the bold, red lines.
Since the story shear on the second level was less than the first level, fewer brackets and fewer panels were necessary to carry the required load. Again using SFS2 screws, the three double-all bracket layout (see Figure 8) gave a capacity of 10.3kips per wall panel. In this case, the exterior walls and single interior wall sufficiently carried the lateral forces. All interior (i.e. non-CLT walls) were designed as typical wood-frame stud walls.

The rest of the design results of the church building are not presented in this thesis, as it is outside the scope of this project. However, a brief overview is provided. The gravity loads were carried predominantly by timber girders and purlins, ranging from 2x8 to 4x12 dimensioned lumber. Additionally, glulam beams were used to carry the loads in both the large, open space on the west side of the building, as well as the three large rooms on the second floor. Typical wood
connections were used for the typical timber purlins. Special connections utilizing angled steel brackets were designed for connecting the glulam beams to the exterior and interior walls. For the diaphragm, typical structural panel sheathing was used on both the first and second story levels. All design calculations and material selection was based on the NDS Wood Manual (AWC 2015). The base was assumed to be slab-on-grade, so no girders were needed on the base level. The slab-on-grade concrete was not designed, and deemed outside of the scope for this thesis.

4.4. Building Seismic Performance

To add this building to the list of current building archetypes, the building needed to not only be designed, but also have its performance tested against some earthquake loading scenarios. This was performed using SAPWood, a modeling program designed specifically to test the nonlinear time history response of wood structures. This program has been thoroughly tested and validated (Pei et al. 2013). Further, this program is relatively simple to use. All modeling data can be input into a spreadsheet and imported to the software. Users can also construct the building within the program. For this study, the spreadsheet methodology was used.

Input into the spreadsheet requires careful attention to detail and consistency when inputting wall locations, lengths, and hysteretic parameters. Not all details are provided here, but the development of hysteretic wall parameters is explained. SAPWood allows for use of four different spring models, including the 10-parameter hysteretic model discussed in this paper and modeled in Figure 5. The “CLT Handbook” was used for selection of wall parameters; the parameters used were the same as those used in development of the load tables utilized in design (Karacabeyli and Douglas 2013, pg. 139). This did require some calculation, as hysteretic parameters were developed for the connectors only, so a wall with two hold-downs and three brackets, for example, would have different hysteretic parameters. The backbone tangent (F0) and
loading path intersection (F1) variables for all connectors were simply summed. Peak displacement (X), the third stiffness factor (r3), and the beta-factor (part of the Kp value from Figure 5) were the same for both connector types, so the value listed for the connector was used for the wall as well. For the other three r-factors (r1, r2, r4) and the alpha-factor (also part of the Kp value), a type of weighted average was used to calculate the wall parameters using the general formula below. Because the stiffness of the wall already takes into account the number and relative stiffness of each connector, a weighted average was used to ensure that the multipliers did not exceed the maximum value. Using another method of combination, such as the root sum of squares, would have led to a double-counting of the overall wall stiffness. The weighted average for calculating the hysteretic parameters of a wall panel with multiple connectors is expressed as

\[
a_{\text{wall}} = \frac{a_{\text{conn,1}} \cdot K_{\text{conn,1}} \cdot N_{\text{conn,1}} + a_{\text{conn,2}} \cdot K_{\text{conn,2}} \cdot N_{\text{conn,2}}}{K_{\text{conn,1}} \cdot N_{\text{conn,1}} + K_{\text{conn,2}} \cdot N_{\text{conn,2}}} \tag{4.4-1}
\]

Where N represents the number of connectors, K represents the stiffness of the connector, and a represents the specific parameter being calculated (i.e. r1, r2, r4, and alpha) of the connector. This was done to account for the overall difference in strength between the hold-downs and the brackets.

Calculation of the CLT wall hysteretic parameters is included in Appendix C.

Calculation of the initial stiffness (K1) proved to be the most intensive calculation. Both the sum of connector stiffness (as used for F0 and F1) and a weighted average would be too conservative. A new approach was used to find the wall stiffness. Amini et al. (2016) tested various CLT panels with varying connectors, among other variables. After performing cyclic loading tests on the 18 wall specimens, the authors compared the curves to find performance variations based on different variables. While connector number was not included in their tests, the figures provided could be manipulated to make those comparisons. To do this, figures provided in the article were overlaid against each other to compare the desired tests. For example, one of the comparisons
made was between tests #18 (with two connectors) and #10 (with four connectors). Test #18 was shown in one figure and test #10 was shown in another figure in Amini et al. (2016). The two figures were overlaid on each other and scaled to match, as shown in Figure 11. After this was done, lines were drawn on the curves in question to compare the initial stiffness (K1) of a varied number of connectors. This was also done for the four r-values, but results showed that connector number did not affect these parameters. The results of the comparison between test #18 (the smaller, black curve in front) and test #10 (the larger, black curve in back) are shown below. As a note, the red curves represent tests that are not of interest of this study. While the black curves are difficult to see in the figure provided, enlarging the picture allowed for a better view of the black curves. Figure 11 is included here as an example of the test performed.

![Figure 11: Overlay of tests #18 and #10 from Amini et al. (2016) with sketched lines](image)

This process was completed for four possible comparisons, tests #18 vs. #10, #18 vs. #19, #11 vs. #9, and #14 vs. #17; the rest of the overlaid test results (similar to Figure 11) are included in Appendix D. The ratios of initial stiffness between the compared tests were compiled into a
table and plotted as shown in Figure 12. Once plotted, a linear relationship was assumed and fitted to the data provided. A linear relationship is assumed to be conservative due to uncertainty. First, the technique used has some uncertainty due to the color of the figures from Amini et al. (2016) and general process of overlaying the figures. As mentioned, the red curves are much clearer, so when attempting to measure the black curves, there is a much greater uncertainty. Additionally, the number of comparisons that could be made was limited as well. The uncertainty is especially true in the #14/#17 test, which shows the greatest variation from linear behavior. Safely using a quadratic curve to fit the results would require more extensive testing and thorough testing. Additionally, wood and seismic design typically uses linear relationships for simplification these often end up being conservative as well. The data and results from the Amini et al. (2016) analysis is presented in Figure 12. The equation provided on the graph was then used for determination of the initial stiffness of the CLT wall panels. Based on the design results of the CLT panels chosen, the multipliers for two, six, and eight connectors were calculated. The K1 value for each wall was then calculated by summing the product of the stiffness of a connector by the connector number stiffness multiplier. All calculations for determining the parameters described above are included in Appendix C.
For the hysteretic parameters of the gypsum wall board (GWB) interior walls, results from Bahmani et al. (2016) were used. The stiffness and force intersection parameters (K1, F0, and F1) are presented in the article as strength per unit length, so this conversion was easily made within the spreadsheet. In terms of lateral force capacity, the strength and stiffness of GWB was assumed insignificant next to what was gained by the CLT’s panels themselves. However, inclusion of the interior walls increases the general stability of the structure in SAPWood. Therefore, interior walls were included in one of the models to check the influence of their presence.

Once all walls were accounted for in the spreadsheet, the model was imported into SAPWood and checked for accuracy. The structure was initially tested to find the fundamental period; once this was accomplished, the intensity measure could be set to spectral acceleration with the target period and damping ratio (0.05 was assumed here). The combination of two suites of seismic excitations were used to test the structure (22 excitations from the ATC-63 suite and 20
excitations included as part of the SAPWood program download). In total, the model subjected the structure to the 42 seismic excitations at 40 different spectral accelerations (from 0.1g to 4.0g at increments of 0.1). This testing run was completed four different times. First only the CLT panels were considered, testing the building in both the X-X direction (previously referred to as the E-W direction) and the Y-Y (N-S) direction. The third and fourth tests tested the X-X and Y-Y directions, respectively, but included the hysteretic performance of the interior walls (further referred to as the ALL walls test).

Both the x-displacement and the y-displacement were measured at the top of the first and second stories. The overall maximum displacement, considering both the x-displacement and y-displacement, was used. This value was converted into interstory drift. The same process was used for the second story drift, and then repeated for the model that included both interior and exterior walls, referred to here as the ALL walls model. After obtaining the maximum interstory drift from the numerical analyses, the probability of exceedance was formulated as

\[
P_E = \frac{N_{\text{exceed},1} + N_{\text{exceed},2}}{168}
\]

where \( N_{\text{exceed},1} \) and \( N_{\text{exceed},2} \) are the number of tests run where the interstory drift exceeded the critical drift limits at the first and second story levels, respectively. The denominator of 168 comes from the 84 tests (42 in the X-X direction and 42 in the Y-Y direction) run at both the first and second story levels.

There were two critical drift limits to investigate. The first was 4% interstory drift. Pang et al. (2010) used 4% drift as the performance expectation for the third performance level, corresponding to collapse prevention. While it is noted that this limit is for wood-frame shear walls, it does provide a general range. Additionally, Karacabeyli and Douglas (2013) note that the lateral load resistance tables (the ones used in building design) for CLT panels are based on
ultimate interstory drift limits of 3.5% to 4%. The first drift limit is meant to capture the ultimate strength of the structure. It is also important to note that the immediate occupancy requirement for drywall is closer to 1%, as it tends to perform very poorly under lateral loads. However, as mentioned in the SAPWood hysteretic parameter discussion, the GWB interior walls have very little effect on the strength of the structure, as compared to the CLT panels. So while the GWB will fail at 1%, the performance objective of collapse prevention will still occur at 4%, controlled by the CLT panels.

The second interstory drift limit used in building analysis was 1%. Recall that 1% corresponded to immediate occupancy, per Pang et al. (2010). Hence, while the first limit captures the ultimate failure of the building, the 1% limit is meant to capture the functionality failure of the building. Additionally, because the building was initially designed for 1% drift under an MCE, any drift limits exceeding 1% would be considered failure.

Once the results were compiled, a lognormal cumulative distribution function (CDF) was fit to the data. Results for the CLT structure are presented in Figure 13. In terms of ultimate failure drift limits, the building performed very well, as only about 80% of the seismic excitations resulted in 4% drift at spectral accelerations of 4.0g. The median probability did not occur until just past a spectral acceleration of 3.0g. In terms of using the performance objective as the failure drift limit, the building had exceptional performance as well, considering that the failure limit is 1% (which corresponds to 1.32in in this building). Probability of failure around 95% did not occur until spectral accelerations of 4.0g were reached. The median probability of exceedance occurred around a spectral acceleration of 2.0g.
When including the hysteresis of the interior walls, as shown in Figure 14, results showed a slight improvement in drift performance. Including the effects of the interior GWB walls increases the spectral acceleration at the median probability by around 0.1 or 0.2, a small difference. It also should be noted that GWB typically fails at high drift, so once the drift capacity of GWB is reached, it will fail and no longer provide lateral resistance.

![CLT Walls - Probability of Exceedance](image-url)

*Figure 13: Probability of exceedance curves for CLT building*
Design of this structure was provided as an example of a social organization utilizing a building designed to higher standards. This building was designed with CLT panels, a relatively new technology, as the lateral force resisting system. However, most of the interior structure was designed using typical wood-frame construction. While cost was not explicitly studied, it could be assumed that this option would be relatively cheap for the amount of strength and seismic performance it provides. It is important that engineers and architects take this building example into account when making decisions for the intended performance of social organization structures. While this building was fictional and has no organization attached to it, the benefits of improved performance of social organization structures is demonstrated in the next chapter.
Chapter 5: Social Capital Index Examples

Results are compiled and presented for three scenarios. The first two sections report findings from interviews performed for select social organizations, and the calculation of the social capital indices based on the initial equations developed in Chapter 3 (Equations 3.2-1 and 3.4-1). Due to the fact that a large amount of the variations in the indices can come from the variables applied as weights, Monte Carlo simulations are performed to model the impact of these variables on the social capital indices. Next, the social organizations are evaluated based on the hazard scenario presented in Section 3.6. Finally, the social capital indices are expanded to include other typical community buildings such as homes, schools, and businesses. The social capital values are compared across building types, also according to the hazard scenario.

5.1. Semi-Structured Interviews for Data Collection

Semi-structured interviews were performed by the author with a number of organizations in the Kansas City area to gain preliminary data for the social capital indices developed in this study. Organizations were chosen from Overland Park, Kansas, the largest city in Johnson County. Eleven organizations were selected, including churches of various religions and denominations, a performing arts center, museums, libraries, and recreation and community centers. From those selected, responses were obtained from eight organizations: four churches, one events center, one library, and two community centers. Additionally, some data and background information was obtained through the organization websites and Google Maps satellite images.

This data was used to quantify the variables used in the indices, as well as to set a basis for converting the variables into a single index value. Interviews of the eight organizations also provided initial input values into the social capital indices. The interview script is provided in Appendix E. The questions included in the interview script were formulated in a way that allowed
for the interview to be performed by any person with knowledge of or within the organization. Many of the interviews were completed by secretaries or administrative assistants.

5.2. Interview Results

Results from the interviews with the social organizations chosen were compiled and input into Microsoft Excel. These are presented in Figure 15. The left, unshaded column for each organization was the list of inputs, which were converted from interview answers into single-cell inputs that could be converted to quantifiable values.

The library and two community centers had the largest membership and visitor numbers, as there are far fewer of these organizations within Overland Park, as compared to religious organizations. These organizations, due to the large number of people using the structure, had a greater number of events than the smaller organizations. The library provided the maximum values of membership and visitor number used in normalizing these two variables (see Equations 3.1-1 and 3.1-2). Many of the other results were consistent with organization type, as all churches had small groups, was older than 25 years, and had a leadership group. Every organization interviewed was able to communicate with members through email, though only half had other methods, such as phone call lists or social media accounts. Funding was consistent by organization types, with churches being funded through donations and the others funded through tax dollars. Only two organizations, the library and Church-2 had any disaster experience. Conversion of the organization social capital variable inputs into quantifiable values was done in the right, shaded column of each organization using the equations defined for each variable in Sections 3.1, with the final organization social capital index calculated below the variables (Equation 3.2-1).
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The building social capital interview results showed a large variation in terms of building age; this will be investigated further in Section 5.3. Nearly all structures had undergone some type of renovation since building construction. The alternative options results were consistent by the organization type, with all of the churches having alternative options while the rest did not. The library, community centers, and events center were all large structures, so it is expected that typical functioning could not be continued elsewhere. All of the study organization were located near residential areas, so all received a value of 1 for the community location variable. In Overland Park, very few structures would receive 0 for this variable due to the layout of the community. Only three structures had made preparations to serve as an emergency shelter, which were the three owned by the city (the library and two community centers). The building components (i.e. the kitchen, large rooms, and others) had more variation between structures without any consistent trend. However, all structures had large, multi-purpose rooms and small rooms, while only one (Community Center-1) had a backup generator. As with the organization social capital variables, conversion of building social capital interview results into quantifiable values was done in the right, shaded column of each organization. The equations from Section 3.3 were used, while calculating the final building social capital index calculated below the variables (Equation 3.4-1).

Results of the organization and building social capital indices of the interviewed organizations are presented in Figure 16 and Figure 17 below. The interview results presented in this section are not based on a specific hazard scenario. Rather, the social capital index values are calculated based on the initial equations developed, Equations (3.2-1) and (3.4-1), respectively.
In terms of organization social capital, the organizations with the highest number of members or visitors have the highest amount of social capital. This is intuitive since the membership number acts as a multiplier to the rest of the variables. However, this allows the index to adequately capture the number of people that are affected by the disaster’s impact on the organization. As a reminder, the indices are meant to be used by decision makers and government leaders for use in finding the organizations that are most important to their community and its functioning. For example, the library has the highest organization index score, while Church-3 has the lowest. Consequently, these also correspond to the highest and lowest membership numbers. While Church-3 is very important to its members, those members are a small fraction of the Overland Park residents. And while the connections built within the church build bonding social capital, and therefore are deeper than those built at the library (per Nakagawa and Shaw, 2004), the library provides many beneficial services to the community, such as English-language or finance classes. Also, even though Church-3 had a low organization social capital score, low organization social capital is not true across all churches; Church-2 had the third highest score.
For the Building Social Capital Index shown in Figure 17, the two highest scores were the two community centers, with the only difference being age of construction. The results show that the emergency shelter variable has a very large effect on building social capital, as was intended to be the case. The three highest scores, the two community centers and the library, were the three that had made preparations to use their shelter as an emergency shelter. Building strength also has a significant impact, as shown with Church-2. Though the building has many of the variables used for achieving high building social capital, its old construction makes the building the lowest score calculated. If the building were constructed in the last ten years, for example, the building would have the fourth largest building social capital index value. Further, the general size of the structure seems to have an impact on building social capital as well. While this was not directly investigated, it is reasonable to assume that the library and two community centers would be much larger structures than that of the churches, for example. Having the size encourages the building owner to consider using their building for aid in the post-disaster setting. Finally, the impact of social capital variables in daily functioning, such as the porch or community location variables, are somewhat dwarfed when looking at the initial equation presented. However, these types of variables are very few in number as compared to the post-disaster variables. While this was intended to point out the impacts of social organizations utilizing their services and connections in the post-disaster setting (i.e. Johnson 2017), variables like emergency shelter dominate the building social capital index score. To differentiate between these impacts, the social capital index values are evaluated based on the three steps of the hazard scenario described earlier.
The final index to be addressed is the Critical Infrastructure Interdependency Index. This index is difficult to capture, largely due to the massive scope. Interdependencies are very reliant on the community being studied. Variations in the overall number of critical infrastructure within the community will have an impact on the physical and logical interdependencies. And while communities are laid out in a calculated way, geographic interdependencies tend to be fairly random between community as well. Adequately calculating the critical infrastructure interdependency matrix would require a deep, in-depth study into an entire community. However, in a large community such as Overland Park, Kansas, this would make the scope of the study very large. Hence, for the sake of this study, the number of critical infrastructure is limited to just three types of critical infrastructure, namely a hospital, a power plant, and a fire station. These are consistent with the critical infrastructure that are analyzed in Section 5.5. Further, geographic interdependencies are omitted from the results due to the randomness and variation seen between different communities. Evaluation of the eight original social organizations based on the critical infrastructure interdependency index is provided in Table 4 below.
None of the social organizations interviewed had any physical interdependencies with the three critical infrastructures. This would be true regardless of the number of critical infrastructure, as critical infrastructure would likely never be dependent on social infrastructure to have continued functionality. However, some logical interdependencies do exist. The churches and community centers have logical interdependencies with each of the critical infrastructure, as the employees of the critical infrastructure will expect places to worship and exercise to return after a natural hazard. Not having these basic necessities could result in the employees leaving the community. The library and performing arts center do not represent a fulfilled need like the other two. With that being said, an entirely accurate representation of the critical infrastructure interdependency index would require an in-depth study, and would change based on community. The results from Table 4 mentioned here are all based on assumptions. Worship and exercise may not be important to one individual, while being able to read books is very important. This is also true based on community.

As typically seen in the Midwest and Southern U.S., it was assumed that religion is important to a large number of the communities, resulting in three logical interdependencies. However, in regions like the western and northeastern U.S. where religion importance is lower, logical interdependencies between churches and critical infrastructure could be assumed to be zero.

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<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Church-2</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Events Center</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Church-3</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Church-4</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Community Center-1</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Community Center-2</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
</tbody>
</table>

*Table 4: Critical Infrastructure Interdependency Index values for social organizations*
Finally, if a government leader needs to select the most important organizations within his or her community, both social capital index values will have to be taken into account. For the sake of this comparison, the maximum values or scales of each index should be noted. As previously mentioned in the development of the equations, the equations have maximum values of 13 and 16, respectively. To ensure that the building social capital index is not overly weighted, the values were normalized on a zero to ten scale for comparison. The interdependency matrix was then added as well; this value was not normalized due to its smaller value and lack of a maximum value.

While the sample size is small, there tends to be a correlation between the buildings and organizations with social capital values. For the library and two community centers, both are high in both indices, and therefore have the highest total social capital, and by quite a large margin. The lack of interdependencies for the library does close the gap between itself and Churches 1 and 2, but the library is still much more important in terms of social capital. Overall the critical infrastructure interdependencies do not have a large effect in the total social capital results, but this would drastically change for a community-wide study. More critical infrastructure would lead to more interdependencies, possibly altering the results seen here. Regardless, Figure 18 makes a strong argument for these three to be prioritized over the other organizations for a government leader. However, for organizations like Church-2, there is a large discrepancy between the organization and building index values. As discussed above, the large discrepancy is likely due to the age of the building. One way to approach this from a decision maker’s point of view would be to encourage Church-2 to improve the structural performance of their building. It is clear that the organization itself is important within the community (Figure 16), but its building lessens its impact. Again, if the building were to be reconstructed or improved, this would drastically increase the total social capital, and make it one of the more important buildings in Overland Park.
Figure 18: Total social capital results from reference interviews

5.3. Monte Carlo Simulation Investigation of Critical Variables in Indices

The social capital indices include a large amount of randomness due to certain variables. For the organization social capital index, while many of the values are binary, the membership number has a large impact on the value of the index. The same is true of the building age variable in the building social capital index. When diving into more specific archetypes of these organizations and infrastructure, as are investigated further in Section 5.5, much of the variation between archetypes comes from the membership number and building age variables. To investigate these impacts, Monte Carlo simulations were performed on both indices. Results were compiled based on 10,000 simulations.

The goal of the organization social capital index simulation was to study the effect of the membership number on the index. For the sake of the simulation, the visitor number variable was set to zero. Membership number and visitor number have the same impact as a multiplier to the rest of the variables and only the maximum value between the two variables is used. Hence, just one of the two variables was selected for the Monte Carlo Simulation. The remaining variables are held constant, with the variables from Church-2 being used to acquire those variables.
For the membership number variable, a lognormal distribution was assumed. A Gaussian distribution is not applicable as it will result in negative values, and insufficient data is available to use another distribution. The mean membership used was 1,600, which corresponds to the value from Church-2’s interview. Standard deviation was assumed to equal half of the membership number (800). The mean and standard deviations chosen model a large church, as was the case with Church-2. These values were first converted into the membership number variable using Equation 3.1-1, then then transformed to lognormal parameters. The resulting lognormal parameters for the membership number variable in the Monte Carlo Simulation were \( \mu = 1.708 \) and \( \sigma = 0.021 \). Once the distribution was calculated, the values were then normalized to ensure the membership number variable was between 0 and 1, as consistent with Equation 3.1-1. Results are presented in Figure 19.

![Simulation of OSCI with Membership Number](image)

*Figure 19: Monte Carlo simulation of OSCI with lognormal distribution for membership number*
The maximum possible value for the organization social capital index of Church-2 is 12.5, when the membership number corresponds to the maximum within that community. According to the Monte Carlo simulation, results center on 11.3, around 90% of the maximum. Nearly all of the results lie between 10.5 and 12, which corresponds to 84% and 96%, respectively. This simulation could be run for small churches, medium churches, or any other type of social organization within a community. While the organization social capital index will still vary based on values of the other variables, Monte Carlo simulations can capture the uncertainty associated with the social capital value of these different social organization archetypes.

The largest variation in the building social capital index is due to the building age variable. While each of the variables impact the building’s capacity to serve as an emergency shelter, none of that has any importance if the building is old and performs poorly under any disaster. As with the organization social capital index Monte Carlo simulation, all variables are held constant, assuming the values from the Church-2 interview. For the Monte Carlo simulation, the building age variable was assumed to have a lognormal distribution, again due to the fact that the building age cannot be negative. For calculating the mean and standard deviation, data was obtained from the US Census Bureau for the construction year of housing units in Overland Park, Kansas (U.S. Census Bureau, 2016). This data is not compiled for businesses or other structures, so data from the housing units was assumed to be consistent with all community buildings in the city. The mean construction year given by the data was 1983 with a standard deviation of 18 years. Plugging into Equation 3.3-1 to measure the building age variable and converting to parameters for the lognormal distribution, \( \mu = 1.796 \) and \( \sigma = 0.512 \). Values were normalized to range from 0 to 1, consistent with the building social capital index. Results are presented in Figure 20.
For the building social capital index of Church-2, the minimum and maximum values were 2.5 and 7, respectively. The minimums were due to the two variables that deal with the building’s capacity to grow social capital, the community location and sidewalk or lawn variables; these were independent of the structure’s age (and consequently, functionality). The simulation shows the center around 2.8, which is around 40% of the maximum. The x-axis limits on Figure 20 only goes up to 5, where the occurrences are already near zero. The mean building age of 1983 pulls the data toward the lower values of social capital. Assuming a newer structure, or perhaps compiling data for social infrastructure construction year, would lead to varying results. Newer structures, or structures with good maintenance, will have higher building social capital.

Finally, when looking at building social capital index, the emergency shelter variable is extremely important and heavily weighted. A second Monte Carlo simulation was run on the
building social capital index using both the building age variable (using a lognormal distribution as above) and emergency shelter variable (random and binary). Results of this Monte Carlo simulation are presented in Figure 21.

Figure 21: Monte Carlo simulation of BSCI using building age and emergency shelter variables

A structure which has made preparations for use as an emergency shelter in the post-disaster setting has a significantly higher building social capital index, as shown in Figure 21 (and initial interview results in Figure 17). The results again centered around 2.8 for tests where the emergency shelter variable was 0. When the emergency shelter variable was assigned a value of 10 in the simulation, the building social capital index values increased the most common index value to around 3.9, a 40% increase. The valley which occurs in the middle (near 3.5) is important to note as well. This value would correspond to the intersection of newer buildings that have not made preparations and older buildings that have made preparations as emergency shelter. The vital importance of making preparations to serve as an emergency shelter are evident in this simulation.
While these Monte Carlo Simulations provide a way to study the uncertainties and variations in the social capital indices due to the membership number, building age, and emergency shelter variables, the Monte Carlo simulations also provide a benefit for community-wide studies. Community leaders can simply measure the social capital of a single social infrastructure archetype (i.e. large church, small church, library, sports arena, and so on), and use a Monte Carlo simulation to estimate the social capital indices for all other social infrastructures within each of those archetypes. This would save time, effort, and money as compared to performing reference interviews with all types of social infrastructure within the community, especially in the case of a large community such as Overland Park, Kansas.

5.4. Comparing Social Capital across Hazard Scenarios

As was discussed in Section 3.6 social capital will vary based on the conditions that the community is experiencing at the time. Hence, the initial social capital index equations were altered to measure the social capital indices at three different phases of a hazard scenario (pre-disaster, hazard event, and recovery). As a reminder, the hazard being discussed is an MCE, so it is assumed that only critical infrastructure remains fully functional. The critical infrastructure interdependency index will not be discussed in this section, as it does not change based on the hazard scenario. The results of the organization social capital under the hazard scenario are presented in Figure 22.
Figure 22: Organization Social Capital Index under different hazard phases

All of the phases show the same general trends, with an increase between the first and second phases and a significant decrease between the second and third phase. Between the first and second phase, the impact of the leadership group is included, so the social capital increases. This jump also corresponds with findings of social capital literature, where social organizations can utilize their connections and place within the community to aid in the hazard event. Because it was assumed that the building was damaged and not yet repaired in the recovery phase, the variables corresponding to typical functioning are no longer included, so there is a significant drop. Hence, simply comparing the organizations based on total score at each phase is insufficient as a standalone measure. The organizations that were previously important are still important (i.e. the library and community centers) are still the largest values. The general trend seen between the second and third stages in Figure 22 demonstrate that a social organization unable to continue after a disaster is damaging to an organization’s social capital, and consequently, the social capital of the community.

These indices provide a measure across social organizations within a community and find those organizations that are the most important in a community. One way this can be done is
through the total values presented in Figure 22. However, another way to measure across the different organizations by importance is to look at the percentage of social capital lost between the first and third stages, to see where the biggest impact of the hazard is felt. A generalized example of this would be a community that has a library with a score of 10 and a church with a score of 5 in pre-disaster conditions. In the recovery phase, the library has a score of 9 while the church’s score drops from 5 to 1. A decision maker may then choose to more closely monitor or focus on the church’s importance to the community, as more will be lost in the event of a disaster. Results of these percentage drops are presented in Figure 23.

The events center, Church-1, and Church 4 all have greater than 50% drop. Hence, a decision could be made to focus on effective recovery for these three organizations to implement better overall community recovery. However, in this case study, Figure 22 shows that these three organizations are also some of the lower values of organization social capital. In this case, focusing on the library and community centers would be more beneficial, but one can see how combining the two comparisons portrayed in Figure 22 and Figure 23 could lead to a clear choice of the most important organizations in terms of social capital.
For the building social capital index, the reader should be reminded that the pre-disaster conditions are looking at the importance of the building, both for building social capital as well as providing aid in the post-disaster setting. However, under the assumed hazard event (and corresponding recovery phase), the building is assumed to have either lost functionality or collapsed. The results of the building social capital index for the three hazard phases (where the hazard event and recovery phases utilize the same index equation) is presented in Figure 24.

![Building Social Capital Index](image)

*Figure 24: Building Social Capital Index under different hazard phases*

As would be expected, the non-functioning or collapsed building leads to significantly reduced building social capital index values in the hazard and recovery phases. Those organizations that were important in the pre-disaster stage are still the more important values, largely due to the preparations these organizations made for utilizing their structure in relief and recovery efforts. Because of these preparations being the main reason for the large jumps in value (as was intended), the most important and relevant structures after a disaster are clearly laid out by looking at the index values from Figure 24. Even though there may be a large drop for the events center, for example, focusing on the library or community centers would still be most beneficial due to benefits it provides.
However, all of these variations are significantly altered in the event that the organization structure is designed to higher standards, as investigated in Chapter 4. In this case, the structures would perform better in the face of the harshest hazards, and it would be more likely that the building would remain functional during the hazard event and recovery phases. If this is the case, higher social capital is generated from the organization and the building, and consequently the corresponding community, due to its continued operation. This allows for social capital to continue to be grown and fostered through small groups and regular events hosted by the organization.

The organization social capital index at the hazard event stage already includes all 13 variables, as it is measuring both the interconnectedness of the members, but also the increased value of relief efforts. If the structure remains standing, it is conceivable that the social capital from the organization during the recovery phase would be the same as that in the hazard event phase. Regular events and typical organization functioning is still creating social capital, and the organization is ready to provide aid the recovery of the community. Hence, if the building remains standing under the hazard scenario, the equation used for organization social capital in the recovery phase would be identical to the one presented initially (see Equation 3.2-1). The increases in social capital due to a building that remains functional is presented in Figure 25.

![Figure 25: Difference in recovery-phase social capital for improved building performance](image-url)
As expected, the results for the organization social capital index greatly increase when building design standards are increased. Looking community functionality curve from Figure 2, the increases in strength and performance shown in Figure 25 lead to increases in community social capital, which pushes a community’s post-disaster functioning to a higher level. And while it may not be conceivable for a community to design every single social organization structure to a higher standard, including just these eight organizations provided a significant increase in community social capital. By summing the index results for the eight organizations, the total score more than doubles from the standard design case to the performance-based designed structures.

The same idea is true for the building social capital index. If the structure remains functional throughout the disaster scenario, the building will have a greater importance as well. Rather than only being able to utilize the structure as a distribution center, the building is now able to serve as an emergency shelter throughout the hazard event and recovery phases. This greatly increases the possible score for the building social capital. The new equation for the hazard event and recovery phase (recall that these were the same in Section 3.6) would be the same as the no hazard or pre-existing conditions equation, which was first presented in Equation 3.4-1. Again, the score between the two phases being measured will vary significantly when the structure remains functional; this is quite intuitive. A building will be more important to the community if the building is still usable.

All of this being said, a community is not made up of solely social organizations. A community is made up of other typical community buildings, like homes, schools, factories, businesses, hospitals, and many more. Community resilience requires all of these different components to be resilient, and to work together towards community resilience. Additionally, social organizations are not the only type of organization or building that increases social capital.
While their social impacts may be smaller, homes and businesses still contribute to the social capital inherent within a community. The variables and method of calculation for the indices built in Chapter 3 allow for social capital to be measured for all building types within a community.

5.5. Comparing Social Capital of Typical Community Buildings to Social Infrastructure

The social capital indices were calculated for fourteen different community building types, separated into four sectors as follows: residences (including single-family homes, apartments, and mobile homes), critical facilities (hospitals, power plants, and fire stations), businesses (restaurants, bowling alleys, shopping malls, gas stations, grocery stores, and factories), and other (schools and office buildings). To measure the social capital indices for these building archetypes, some variable definitions were altered or clarified. Only those with alterations are discussed; variables not mentioned here utilize the same definition as listed in Sections 3.1 and 3.3.

Residences. A household does not have a membership program, however, there is a group of people that regularly use the home. Hence, the membership number variable counts those who reside within the home. Visitors would be house guests such as friends or extended families, or any other person to come to the residence that is not part of the immediate family. For organization age, it could be argued that the length of time the family or group has been together could be used. However, in this study, families are not looked at as organizations, so this factor is omitted. The organization age variable is looking for a general feeling of importance based on length of time together, but it is assumed that the nature of a family’s connections is independent of time spent together. Additionally, because the family structure is not considered an organization, parents or family heads are not considered a leadership group. In terms of the building, most variables are straight-forward, but to clarify, the living room or den was not considered a multi-purpose room.
Critical Facilities. All critical facilities would have no members, as none of the visitors have a consistent, direct connection to the critical facilities (outside of employees).

Businesses. For the business sector, the visitor number variable is the same as for social infrastructure. For membership, a count of the number of people engaged in a type of loyalty program was used. Where loyalty programs do not exist, an estimation of frequent visitors (e.g. those who fill up with gas at the same station once per week) can be used. However, when it is included within the building social capital index, the membership variable is typically smaller than the visitor number value, so visitor number is the more relevant measure for businesses. For organization age and leadership, if the business is part of a chain, the age and leadership group of the chain itself is used. For those that are individual businesses, the age of the business is used, but the ownership or management group is not included here. This is due to the fact that these businesses will typically be smaller in size, and therefore have a smaller leadership group. In terms of a post-disaster setting, the smaller group will be more stretched and less able to perform outreach or aid duties. Chain businesses will likely have a larger governing body, better capable of serving in the post-disaster setting. The rest of the variables are unchanged.

Other. The two archetypes included in this section are schools and office buildings. The office building archetype is meant to describe buildings that house either just one or more than one business or corporation. Both include a number of frequent users, typically not defined as members. However, for this study, the number of students and employees, respectively, are included. These frequent users are not included in the visitor numbers, so the visitor variable is typically very small. This assumption is the same as was used for the residential set of archetypes. Small groups would be present in a multi-business office building, but
not within a single-business office. For the regular events variable, the five school or work
days per week are included, because each of these events provide a method for the
organizations members to get together.
The social capital indices were calculated for each of the community building types mentioned
above, including additional archetypes in the single-family home and hospital archetypes. Four
archetypes were developed for single-family homes as follows:

- A couple with two children in a relatively new home
- A couple with four children in an older home
- An elderly couple in a new home
- A large family (couple with five children) living in a farmhouse (old construction)

Additional archetypes developed for the hospital included a large, “state-of-the-art”
hospital and an older hospital. Additional archetypes were developed for these two building
categories as there is significant variation in the variables measured in the social capital indices.
For the remainder of the building types, the variables that change are the membership and visitor
numbers for the organization index and building age for the building index, which tend to be much
more random. While social organization values were obtained through interviews, typical
community building values were obtained through assumptions and research. Reasoning and
description for each of the variables, as well as references to data used, is included in Appendix F.

Figure 26 provides a breakdown of the average organization and building social capital
index results, respectively, at the no hazard or pre-disaster level for each building sector. The
average of the buildings in each sector was taken to normalize the results, as eight social
organizations were measured while only four essential facilities were measured, for example.
Figure 26: Organization (left) and Building (right) social capital index values at the no hazard phase

Figure 26 shows that social capital is better grown and manifested in social organizations than any other building sector, accounting for nearly 50% of the organization social capital. The next largest sector, the business sector, accounts for around 25%. This sector includes many types of businesses that could also be considered social organizations like bowling alleys, restaurants, and movie theaters. An argument could be made that these buildings are indeed social organizations; DHS groups these retail and entertainment subsectors with the public assembly subsectors. Including these as social organizations would change the percentage to around 75%. It should be noted here that taking an average of the index values is not entirely representative of a community, as a town or city will include many more residences than the other organization (and building) sectors. This is discussed in the study of all community organizations and infrastructure under a hazard scenario. However, the size the fraction of Figure 26 taken by social organizations presents the impact that social organizations can have on the overall social capital of a community.

Building social capital average values exhibit much less variation, but critical facilities and social organizations exhibit the largest share of the graph. This would make sense, as these structures are typically larger and more recently constructed, making them better suited for providing aid in the disaster setting. Part of the reason that the results do not show much variation
would be due to the use of building age as a multiplier. This variable is has a greater deal of scatter, leading to a large amount of scatter in the building social capital index results. Further, in both the organization and building indices, the social organizations will tend to have a wider range of values, as is evident in Figure 27 and Figure 28. This will skew the data slightly away from social organizations, as smaller organizations like Church-3 will take away from the immense social capital impact that the library has.

Results of the organization social capital index and building social capital index values for all building types under the three phases of the hazard scenario are provided in Figure 27 and Figure 28, respectively.
Figure 27: OSCI for social organizations and typical community buildings under hazard scenario.
Figure 28: BSCI for social organizations and typical community buildings under hazard scenario
Figure 27 shows that many of the social organizations have a larger impact on social capital than typical community buildings, where the organizations used in the reference interviews show higher results. As with Figure 26, the business sector showed high social capital values as well, due to the large amount of people that use these structures and the interaction that occurs. The high school and office buildings, while they may not be socially-based like some of the businesses, they do include a high amount of interaction between users so a high organization social capital index score makes sense.

In the context of the community as a whole, the social capital of the residential set of community buildings (single-family homes, apartments, and mobile homes) are interesting. Their organization social capital values are minimal; they are the lowest non-zero result of all building types. Though when these results are combined with the fact that a city includes thousands or tens of thousands more homes than social organizations, the residential sector suddenly becomes greater in comparison than the other sectors. However, by looking deeper into the variables that contribute to the social capital of the residential buildings, it is seen that the only variables are the user number variables and the change in membership. If the assumption that the family unit serves as membership is changed, then the social capital index will go to zero. In terms of the community as a whole, this would likely be more correct. While the family unit is important in terms of recovery, its impact is not socially-based. The family will likely stay intact regardless of the hazard, and the true value of being connected to the community as a whole is not captured within the “organization” of a family residence.

Building social capital is less dependent on building archetype, as its variables are more based on the structure’s characteristics. Social organizations still tend to have higher results as their structures tend to be larger, allowing for a better capacity to serve in the post-disaster setting.
The same is true of hospitals and schools as well. As an important note, the results of building social capital index will vary significantly based on structure age. While some general assumptions can be made (i.e. older farmhouses or newer, state-of-the-art hospitals), these will vary by structure and by community.

Again, the lower score of the residences will seem to be offset by the large number of homes that exist within a community. Unlike the organization social capital case, the impact of homes on building social capital is much more prominent. If possible, displaced families may choose to first find shelter with close friends or family members. However, as was pointed out in Chapter 4, one of the goals of this study was to also advocate for improved design of social organization structures due to their importance in terms of social capital in the post-disaster setting. While residences do have importance, it is much more difficult to advocate for (and financially accomplish) higher performing homes due to the large number of residences within a community.

The same is true in terms of organization social capital.

Finally, the critical infrastructure interdependency index for the other community buildings is provided in Table 5. The same assumptions used when calculating the critical infrastructure interdependency index for social infrastructure are used here. As a reminder, due to the complexity of measuring all interdependencies in Overland Park, only three critical infrastructures are considered (a hospital, power plant, and fire station), and geographic interdependencies are omitted due to the randomness between communities this value has.
Table 5: Critical Infrastructure Interdependency Index values for other community buildings

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Physical</th>
<th>Logical</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Family Home: Couple, 2 young kids</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Single-Family Home: Couple, 4 teen kids</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Single-Family Home: Elderly couple</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Single-Family Home: Couple, 5 kids, farm</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Apartment Complex</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Mobile Home</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>KU Medical Center</td>
<td>N/A</td>
<td>2 (power and fire station)</td>
<td>2</td>
</tr>
<tr>
<td>Blue Valley Hospital</td>
<td>N/A</td>
<td>2 (power and fire station)</td>
<td>2</td>
</tr>
<tr>
<td>Power Plant</td>
<td>2 (hospital and fire station)</td>
<td>N/A</td>
<td>4</td>
</tr>
<tr>
<td>Fire Station</td>
<td>1 (hospital)</td>
<td>N/A</td>
<td>2</td>
</tr>
<tr>
<td>Restaurant</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Bowling Alley</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Shopping Mall</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Gas Station</td>
<td>3 (1 per CI)</td>
<td>N/A</td>
<td>6</td>
</tr>
<tr>
<td>Grocery Store</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Factory</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>High School</td>
<td>N/A</td>
<td>3 (1 per CI)</td>
<td>3</td>
</tr>
<tr>
<td>Office Building</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>

The only physical interdependencies that exist are critical infrastructures and the gas stations. All critical infrastructures within a community are dependent on power plants to properly and continually function. The hospital requires the fire station and other emergency services to respond and bring the injured to the hospital. While the hospital is vitally important itself, it does not have any physical interdependencies with the other critical infrastructure. Finally, gas stations are assigned three physical interdependencies because they are required to maintain functionality of each of these places, whether it be through employees getting to work or emergency services being able to go out and provide aid. None of the other typical community buildings are required in the immediate post-disaster setting, as alternatives can be made for housing, amenities can be
neglected (such as restaurants, shopping malls, or bowling alleys), and jobs or schooling may be temporarily suspended, for example.

Logical interdependencies do exist for the other community buildings, however. The buildings in the residences sector are assigned one logical interdependency for each critical infrastructure, as employees of the critical infrastructure will require a long-term housing option in the weeks or months following a disaster. Lack of a home could lead to these employees leaving the community. The same is assumed about grocery stores, as employees need ways to feed themselves, and schools for sending their children to school, if applicable. Further, logical interdependencies are assigned to restaurants and shopping malls, as these, similar to the social organizations, affect the overall sense of community and make a place feel like home. As a reminder, these interdependencies under the hazard scenario are unchanged, as the interdependencies exist regardless.

Finally, as was done with the social organizations in Section 5.2, each of the three indices are combined to calculate the total social capital of each organization and infrastructure in the community. As was done in Section 5.2, the initial equations developed are used, with the organization and building social capital indices being normalized on a 0 to 10 scale once again.

Adding all of the indices together allows for government leaders to find the most impactful social organizations and buildings within their community in terms of social capital. Adding in the effects of the critical infrastructure interdependency index lowers the total amount of variation in the indices, especially in the residential sector. As was the case with the individual indices, the larger social organizations provide the greatest amount of social capital to a community. The same is true of the businesses and schools, or places where there is a high amount of social interaction.
Figure 29: Total Social Capital for all community buildings
Chapter 6: Conclusions and Recommendations

This study provided a method to quantify social capital within a community through the development of three indices. The first index measures social capital facilitated through social organizations, the second index measures social capital facilitated through the building which houses that social organization, and the third index measures the interdependencies each of those organizations has with critical infrastructure.

This thesis offers several new contributions to the current state-of-knowledge. There are multiple reasons why this thesis is important. Firstly, in most community resilience frameworks, there is a lack of methodology for quantifying the community capitals. This study provides a way to measure social capital, one of the community capitals. Further, the methodology developed here can be applied to prioritize organizations and infrastructure based on social capital. As with the ice-skating rink in Buffalo Creek (Erikson 1978), government leaders can evaluate the social organizations and infrastructure within their community and prioritize them based on their importance to the community. The impacts of prioritizing social organizations has two possible manifestations. First, following an extreme event, the social capital measures produced in this thesis could be used to prioritize rebuilding and the redistribution of recovery resources in a new way that promotes social capital, and will thereby improve the quality of recovery.

Alternatively, this could lead to another look at risk categories in ASCE 7, for example, where “risk categories,” or more importantly, design levels, are selected and legally mandated base on how those buildings benefit the community considering fundamental social dynamics, such as social capital.

These are not the only infrastructure within a community that addresses needs, however. Currently, most buildings (including social infrastructure) are designated as Risk Category II.
While this does offer simplification, using Risk Category II for most community buildings is missing the fact that all buildings provide a vital need to community members. For social organizations, that need is social capital, manifested through relationships and a sense of community. The current approach of risk categories, and consequently, structural design prioritizes only design strength and performance. However, as community resilience research advances and its manifestations are better understood, perhaps the current use of risk categories should be reevaluated. While community resilience does have an aspect of strength (robustness), equal importance is also placed on the other aspects (resourcefulness, rapidity, and redundancy). Hence, this study advocates for a transformation of the ASCE 7 risk categories to a more equally weighted approach that prioritizes design standards, along with mitigation and allocation of repair and recovery resources, as these are vital to community resilience. While this may lead to a more complicated design approach, it will also be a more holistic approach that improves the performance of communities.

As with all progress, this work and methodology has its limitations, including the variance in some of the measure used in the indices, and the complexity of justly computing the indices for every building in a city. Due to the fact that the social capital indices were constructed in a way that allowed for the variables to be obtained through 15-20 minute interviews with administrative assistants, oversimplification became possible. For example, while variables were used and developed to account for the depth of connections between members, such as organization events or small group capabilities, the depth of connection may not be fully captured by these variables. In terms of oversimplification, one example is of the building social capital index variable of building age. This variable is meant to capture the strength of the structure, through assumptions made about design code at the time and approximate “wear-and-tear” of the structure over time.
However, truly knowing those items about the structure would require in-depth studies of the building blueprint and a structural inspection.

Two other limitations of this study deal with the assumption of the hazard scenario. First, the seismic hazard scenario is simplified to assume that all structures in the community experience the same accelerations. However, true community-level hazard scenarios would utilize different hazard events experienced by each structure, and consequently different amounts of damage. Secondly, the hazard scenario used assumes that during the hazard event, each social infrastructure loses functionality. Consequently, when measuring the organization social capital index, it is assumed that all organization functions cease, due to the organization’s close ties with its physical space. In reality, the organization may have multiple buildings or be able to continue operation through finding a new building.

The intersectionality of the seven capitals needs research. For example, improving social capital may impact the economic capital of a community, in that well-connected community members are quicker to go out and spend their money locally. If the definition of social infrastructure is expanded to include those socially-based businesses (i.e. bowling alleys, shopping malls, or restaurants) mentioned earlier, keeping those operations functional in the post-disaster setting also impacts the economic capital.

A secondary recommendation for further research involves the hazard scenario and timeline. The hazard scenario used in this study calculates index values at an initial or pre-disaster functioning level, hazard event level, and a recovery level. The hazard event phase was meant to capture the immediate response of the organization and structure, such as the first day or two after a disaster. The recovery phase was then assumed to be the weeks or months following the disaster. The hazard scenario could be further expanded, looking at multiple points along the recovery
timeline. Further, the impacts of multiple disasters were not studied in this thesis. For example, having gone through one hazard scenario may impact the pre-disaster phase for the second hazard scenario experience by the community. If the community experienced effective recovery during the previous hazard, it may improve the connection and social cohesion between members, resulting in higher pre-disaster conditions for the next hazard. The previous disaster experience variable captures only a small part of that impact.

A final recommendation for future research is development of a methodology for measuring or quantifying resilience. The four R’s from Bruneau et al. (2003) are effective measures, yet are difficult to understand in a full community setting. Referring to the extensive nature of community resilience, measurement proves to be difficult as a detailed resilience measurement would include a large number of variables. This study developed a quantifiable method for measuring the social capital within a community. By combining the social capital indices developed with effective quantifiable measures for the remaining six community capitals from NIST (2015), those measures could be compiled into a single measure for community resilience.

For the engineering community, the practices modeled in Chapter 4 are recommended to be pursued. While they may not be possible in all situations, the positive impacts in the disaster setting of high-performing structures are evident. For government leaders and those involved with resilience at the community level, it is important to discuss those practices with owners of social organizations. As a consequence of this.
of this, these owners are aware of the impacts of their organization to the community as a whole. Further, discussing these impacts may also encourage those organizations to make preparations to provide relief in times of disaster, which is shown in Chapter 5 to have a significant impact on total social capital. The community functionality curve from Figure 2 serves as a reminder as to the benefits of social capital. Including the benefits and improving social capital in a community will improve a community’s capability to recovery and raise the community’s functionality during regular, pre-disaster conditions in the future.
Chapter 7: References


City and County of San Francisco. (2016). "Resilient San Francisco."


Triplett, Mike. (2016). "Ten years ago, a blocked punt symbolized the 'Rebirth' of the Saints and New Orleans." ESPN.


List of Appendices

Appendix A: USGS Design Map .............................................................. 1 page
Appendix B: SDDD Calculations and Floor Weight Details ........................................... 14 pages
Appendix C: Calculation of Hysteric Wall Parameters ................................................. 1 page
Appendix D: Figure Overlays from Amini et al. (2016) .............................................. 1 page
Appendix E: Organization Interview Script .................................................................. 4 pages
Appendix F: Reasoning and Assumptions for Community Building Index Values ........ 2 pages
Appendix G: .............................................................. 10 pages

140
**User-Specified Input**

**Building Code Reference Document**
ASCE 7-10 Standard  
(which utilizes USGS hazard data available in 2008)

**Site Coordinates**  
37.77503°N, 122.41949°W

**Site Soil Classification**  
Site Class D – “Stiff Soil”

**Risk Category**  
IV (e.g. essential facilities)

**USGS-Provided Output**

\[
S_s = 1.500 \text{ g} \\
S_S = 1.500 \text{ g} \\
S_{DS} = 1.000 \text{ g} \\
S_t = 0.638 \text{ g} \\
S_{M1} = 0.957 \text{ g} \\
S_{D1} = 0.638 \text{ g}
\]

For information on how the SS and S1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the “2009 NEHRP” building code reference document.

For PGA, T_L, C_RS, and C_R1 values, please view the detailed report.

Although this information is a product of the U.S. Geological Survey, we provide no warranty, expressed or implied, as to the accuracy of the data contained therein. This tool is not a substitute for technical subject-matter knowledge.
### Appendix B: SDDD Calculations and Floor Weight Details

<table>
<thead>
<tr>
<th></th>
<th>Interstory drift limit - Immediate Occupancy for MCE</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Probability of non-exceedance</td>
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<tr>
<td>1.88</td>
<td>CNE</td>
</tr>
</tbody>
</table>

\( \beta \) - assumed with ground motion uncertainty (0.4) and measurement uncertainty (0.6)

<table>
<thead>
<tr>
<th>Bc Calculation</th>
<th>Cc Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \zeta_{int} )</td>
<td>( \zeta_{eff} )</td>
</tr>
<tr>
<td>( K_s/K_0 )</td>
<td>( C_{cs} )</td>
</tr>
<tr>
<td>( \zeta_{hyst} )</td>
<td>( C_{c1} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Bc</th>
<th>1.71</th>
<th>Cc</th>
<th>1.65</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>h_eff</th>
<th>19.5</th>
<th>ft</th>
<th>( V_b )</th>
<th>716.6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \Delta_{ef} )</td>
<td>1.24</td>
<td>in</td>
<td>( V_s )</td>
<td>716.6</td>
</tr>
</tbody>
</table>

| | W_{eff} | 435.2 | kip | \( V_s \) | 552.9 |

<table>
<thead>
<tr>
<th></th>
<th>W*( \Delta_0 )</th>
<th>( C_v ) * h_0</th>
<th>W*( \Delta_0^2 )</th>
<th>( V_s )</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>176.1</td>
<td>0.228</td>
<td>0.000</td>
<td>86.8</td>
</tr>
<tr>
<td>2</td>
<td>297.4</td>
<td>0.772</td>
<td>0.772</td>
<td>586.5</td>
</tr>
</tbody>
</table>

| \( \Sigma \) | 473.5 | 0.000 | 19.5 | 673.3 |
Shaded Area:
4 x 12 Girders (16” O.C.)
First Floor

\[ D_{412.16} = \frac{W_{df}(4\text{in})(12\text{in})}{16\text{in}} = 7.8 \cdot \text{psf} \]

\[ A_{412.16} = 3421.5\text{ft}^2 \]

\[ W_{412.16} = D_{412.16} \cdot A_{412.16} = 26.7 \cdot \text{kip} \]
Appendix B: SDDD Calculations and Floor Weight Details

**Shaded Area:**
2 x 10 Girders (16” O.C.)
First Floor

\[
D_{210.16} := \frac{W_{\text{diff}} \cdot (2\text{in}) \cdot (10\text{in})}{16\text{in}} = 3.25 \cdot \text{psf}
\]

\[
A_{210.16} = 188 \text{ft}^2
\]

\[
W_{210.16} := D_{210.16} \cdot A_{210.16} = 6.1 \cdot \text{kip}
\]
Appendix B: SDDD Calculations and Floor Weight Details

**Shaded Area:**
2 x 8 Girders (16" O.C.)
First Floor

\[
D_{28.16} := \frac{W_{\text{dfl}} \cdot (2\text{in}) \cdot (8\text{in})}{16\text{in}} = 2.6\text{-psf}
\]

\[
A_{28.16} := 1118.25\text{ft}^2
\]

\[
W_{28.16} := D_{28.16} \cdot A_{28.16} = 2.9\text{-kip}
\]
Appendix B: SDDD Calculations and Floor Weight Details

Shaded Area:
15/32" Floor Sheathing
First Floor

\[ D_{15.32} := 3 \text{psf} \cdot \left(\frac{15}{32}\right) = 1.406 \text{psf} \]

\[ A_{15.32} := 6420.75 \text{ft}^2 \]

\[ W_{15.32} := D_{15.32} \cdot A_{15.32} = 9 \text{-kip} \]

Shaded Area:
Misc. (Ceiling, HVAC, etc.)
First Floor

\[ D_{m1} := 5 \text{psf} \]

\[ A_{m1} := A_{15.32} = 6420.75 \text{ft}^2 \]

\[ W_{m1} := D_{m1} \cdot A_{m1} = 32.1 \text{-kip} \]
Appendix B: SDDD Calculations and Floor Weight Details

**Bold Lines:**
CLT Walls - First Floor

\[
P_{\text{clt1}} = 709\text{ft} \quad \text{(perimeter)}
\]

\[
t_{\text{clt1}} = 4.125\text{in} \quad \text{(thickness)}
\]

\[
h_{\text{clt1}} = 11\text{ft} \quad \text{(height)}
\]

\[
V_{\text{clt1}} = P_{\text{clt1}} \cdot t_{\text{clt1}} \cdot h_{\text{clt1}} = 2680.906\text{ft}^3
\]

\[
W_{\text{clt1}} = V_{\text{clt1}} \cdot W_{\text{dfl}} = 83.644 \text{kip}
\]
Appendix B: SDDD Calculations and Floor Weight Details

Remainder of the first floor walls are light-frame walls

\[ P_{lw1} := 726.5 \text{ ft} \quad h_{lw1} := 11 \text{ ft} \quad A_{lw1} := P_{lw1} \cdot h_{lw1} = 7991.5 \text{ ft}^2 \]

\[ D_{lw1} := \frac{W_{dfl} \cdot (2 \text{ in}) \cdot (6 \text{ in})}{16 \text{ in}} = 1.95 \text{ psf} \quad W_{lw1} := D_{lw1} \cdot A_{lw1} = 15.583 \text{-kip} \]

**First Floor Weight Summary**

4 x 12 Girders \[ W_{412.16} = 26.688 \text{ kip} \]

2 x 10 Girders \[ W_{210.16} = 6.113 \text{ kip} \]

2 x 8 Girders \[ W_{28.16} = 2.907 \text{ kip} \]

15/32 Diaphragm \[ W_{15.32} = 9.029 \text{ kip} \]

Misc. \[ W_{m1} = 32.104 \text{ kip} \]

CLT Walls \[ W_{clt1} = 83.644 \text{ kip} \]

Light-frame Walls \[ W_{lw1} = 15.583 \text{ kip} \]

\[ W_{\text{floor1}} := W_{412.16} + W_{210.16} + W_{28.16} + W_{15.32} + W_{m1} + W_{clt1} + W_{lw1} \]

\[ W_{\text{floor1}} = 176.1 \text{-kip} \]

\[ g = 386.089 \frac{\text{in}}{\text{s}^2} \]

\[ W_{pa1} := \frac{W_{\text{floor1}} \cdot 1}{g \cdot A_{15.32}} \quad W_{pa1} = 0.000000493 \text{ kip \cdot s}^2 / \text{in} \cdot \text{in}^2 \]
Appendix B: SDDD Calculations and Floor Weight Details

**Shaded Area:**
4 x 10 Girders (48" O.C.)
Second Floor

\[ D_{410.48} := \frac{W_{\text{diff}} \cdot (4\text{in}) \cdot (10\text{in})}{48\text{in}} = 2.167 \text{ psf} \]

\[ A_{410.48} := 14979.25\text{ ft}^2 \]

\[ W_{410.48} := D_{410.48} \cdot A_{410.48} = 32.5 \text{ kip} \]
Appendix B: SDDD Calculations and Floor Weight Details

**Shaded Area:**

4 x 8 Girders (48” O.C.)
Second Floor

\[
D_{48.48} := \frac{W_{\text{dfl} \cdot (4\text{in}) \cdot (8\text{in})}}{48\text{in}} = 1.733\text{ psf}
\]

\[
A_{48.48} = 2811.25\text{ft}^2
\]

\[
W_{48.48} := D_{48.48} \cdot A_{48.48} = 4.9\text{kip}
\]
Appendix B: SDDD Calculations and Floor Weight Details

Shaded Area: 23'-32" Floor Sheathing

Second Floor

Shaded Area: Misc. (Ceiling, HVAC, etc.)

Second Floor

\[
\begin{align*}
D_{32} & = 3\text{ psf} \quad A_{23} = 16\text{ft} \times 110.5\text{ ft} = 17790.5\text{ ft}^2 \\
W_{23} & = D_{32} \times A_{23} = 3 \times 17790.5 = 53371.5\text{ lbs} \\
A_{m2} & = 5\text{ psf} \\
W_{m2} & = D_{m2} \times A_{m2} = 5 \times 89 = 445\text{ kip}
\end{align*}
\]
Appendix B: SDDD Calculations and Floor Weight Details

Shaded Area:
(6) 6.75" x 42" Glulams (15'-6" O.C.)
Second Floor

\[ D_{gl} := \frac{W_{dl} \cdot (6.75\text{in}) \cdot (42\text{in})}{15.5\text{ft}} = 3.963 \cdot \text{psf} \]

\[ A_{gl} := (80.5\text{ft}) \cdot (110.5\text{ft}) = 8895.25 \cdot \text{ft}^2 \]

\[ W_{gl} := D_{gl} \cdot A_{gl} = 35.3 \cdot \text{kip} \]
Shaded Area: (6) 10.75" x 18" Glulams (18' 0" O.C.)

Second Floor

\[
\begin{align*}
D_{gs} &= \frac{W_{df} (10.75 \text{in}) (18 \text{in})}{18 \text{ft}} \\
A_{gs} &= \frac{553.1 \text{ft}^2}{D_{gs}} \\
W_{gs} &= D_{gs} \cdot A_{gs} = 12.9 \text{kip}
\end{align*}
\]
Appendix B: SDDD Calculations and Floor Weight Details

CLT Walls - Second Floor

\[ P_{clt2} = 653.5 \text{ft} \]
\[ t_{clt2} = 4.125 \text{in} \]
\[ h_{clt2} = 11 \text{ft} \]

\[ V_{clt2} = P_{clt2} \cdot t_{clt2} \cdot h_{clt2} = 2471.047 \text{ft}^3 \]

\[ W_{clt2} = V_{clt2} \cdot W_{df1} = 77.097 \text{kip} \]
Appendix B: SDDD Calculations and Floor Weight Details

Remainder of the second floor walls are light-frame walls

\[ P_{lw2} := 527\text{ft} \quad h_{lw2} := 11\text{ft} \quad A_{lw2} := P_{lw2} \cdot h_{lw2} = 5797\text{ft}^2 \]

\[ D_{lw2} := \frac{W_{dfl} \cdot (2\text{in}) \cdot (4\text{in})}{16\text{in}} = 1.3\text{psf} \quad W_{lw2} := D_{lw2} A_{lw2} = 7.536\text{-kip} \]

Second Floor/Roof Weight Summary

4 x 10 Girders \quad W_{410.48} = 32.455\text{kip}

4 x 8 Girders \quad W_{48.48} = 4.873\text{kip}

23/32 Diaphragm \quad W_{23.32} = 38.361\text{kip}

Misc. \quad W_{m2} = 88.953\text{kip}

Large Glulams \quad W_{gl} = 35.251\text{kip}

Small Glulams \quad W_{gs} = 12.884\text{kip}

CLT Walls \quad W_{clt2} = 77.097\text{kip}

Light-frame Walls \quad W_{lw2} = 7.536\text{kip}

\[ W_{\text{roof}} := W_{410.48} + W_{48.48} + W_{23.32} + W_{m2} + W_{gl} + W_{gs} + W_{clt2} + W_{lw2} \]

\[ W_{\text{roof}} = 297.4\text{kip} \]

\[ g = 386.089 \frac{\text{in}}{s^2} \]

\[ W_{pa2} := \frac{W_{\text{roof}}}{g} \cdot \frac{1}{A_{23.32}} \quad W_{pa2} = 0.00000301 \frac{\text{kip}}{\text{s}^2} \cdot \frac{1}{\text{in}^2} \]
Appendix C: Calculation of Hysteretic Wall Parameters

Parameters from CLT Handbook (Karacabeyli and Douglas 2013)

Htt16 hold-down

\[
\begin{align*}
K_{0h} &= 25000 \text{ lbf/in} \\
F_{0h} &= 9000 \text{lbf} \\
F_{1h} &= 400 \text{lbf} \\
X_h &= 2 \text{ in} \\
a_h &= 0.75 \\
b_h &= 1.10 \\
r_{1h} &= 0.002 \\
r_{2h} &= -0.30 \\
r_{3h} &= 1.00 \\
r_{4h} &= 0.05
\end{align*}
\]

SFS2 screw

\[
\begin{align*}
K_{0b} &= 1600 \text{ lbf/in} \\
F_{0b} &= 1200 \text{lbf} \\
F_{1b} &= 40 \text{lbf} \\
X_b &= 2 \text{ in} \\
a_b &= 0.5 \\
b_b &= 1.10 \\
r_{1b} &= 0.005 \\
r_{2b} &= -0.40 \\
r_{3b} &= 1.00 \\
r_{4b} &= 0.01
\end{align*}
\]

Stiffness Multipliers... (from Amini 2016 study)

\[
\begin{align*}
KM(n_c) &= 1.2833n_c - 0.95 \\
KM_2 &= KM(2) = 1.6166 \quad (2 \text{ connectors}) \\
KM_6 &= KM(6) = 6.7498 \quad (6 \text{ connectors}) \\
KM_8 &= KM(8) = 9.3164 \quad (8 \text{ connectors})
\end{align*}
\]

Story 1 CLT...

9' x 12' panels, (2) hold downs, (4) DA brackets (8 total)

\[
\begin{align*}
K_{01} &= K_{0h}(KM_2) + K_{0b}(KM_8) = 55.3 \text{ kip/in} \\
F_{01} &= F_{0h}(2) + F_{0b}(8) = 27.6 \text{ kip} \\
F_{11} &= F_{1h}(2) + F_{1b}(8) = 1.12 \text{kip} \\
r_{11} &= \frac{r_{1h}K_{0h}(2) + r_{1b}K_{0b}(8)}{K_{0h}(2) + K_{0b}(8)} = 0.00261 \\
r_{21} &= \frac{r_{2h}K_{0h}(2) + r_{2b}K_{0b}(8)}{K_{0h}(2) + K_{0b}(8)} = -0.32038 \\
a_{11} &= \frac{a_{h}(K_{0h})(2) + a_{b}(K_{0b})(8)}{K_{0h}(2) + K_{0b}(8)} = 0.69904
\end{align*}
\]

Story 2 CLT...

Both west wall (9' x 12' panels) and rest of walls (6' x 12' panels) utilize (2) hold downs and (3) DA brackets (6 total)

\[
\begin{align*}
K_{02} &= K_{0h}(KM_2) + K_{0b}(KM_6) = 51.2 \text{ kip/in} \\
F_{02} &= F_{0h}(2) + F_{0b}(6) = 25.2 \text{ kip} \\
F_{12} &= F_{1h}(2) + F_{1b}(6) = 1.04 \text{kip} \\
r_{12} &= \frac{r_{1h}K_{0h}(2) + r_{1b}K_{0b}(6)}{K_{0h}(2) + K_{0b}(6)} = 0.00248 \\
r_{22} &= \frac{r_{2h}K_{0h}(2) + r_{2b}K_{0b}(6)}{K_{0h}(2) + K_{0b}(6)} = -0.31611 \\
a_{22} &= \frac{a_{h}(K_{0h})(2) + a_{b}(K_{0b})(6)}{K_{0h}(2) + K_{0b}(6)} = 0.70973
\end{align*}
\]

Gypsum Wall Board - from Bahmani et al 2016

\[
\begin{align*}
K_{0g} &= 450 \text{ lbf/in} \\
F_{0g} &= 100 \text{lbf/in} \\
F_{1g} &= 6.5 \text{lbf/in} \\
F_{1g} &= 6.5 \text{lbf/in} \\
r_{1g} &= 0.023 \\
r_{2g} &= -0.040 \\
r_{3g} &= 1.01 \\
r_{4g} &= 0.010 \\
X_g &= 1.1 \text{in} \\
a_g &= 0.80 \\
b_g &= 1.10
\end{align*}
\]
Test #18 (Fig. 13) - 2 connectors (small curve, black line) vs. Test #10 (Fig. 11) - 4 connectors (large curve, black line)
Test #18 (Fig. 13) - 2 connectors (small curve, black line) vs. Test #19 (Fig. 12) - 5 connectors (large curve, black line)

Test #18 (Fig. 13) - 2 connectors (small curve, black line) vs. Test #19 (Fig. 12) - 5 connectors (large curve, black line)
Test #11 (Fig. 13) - 2 connectors (small curve, red line) vs. Test #09 (Fig. 10) - 3 connectors (large curve, black line)
Test #17 (Fig. 11) - 3 connectors (small curve, red line) vs. Test #14 (Fig. 10) - 4 connectors (large curve, red line)

Test #17 (Fig. 11) - 3 connectors (small curve, red line) vs. Test #14 (Fig. 10) - 4 connectors (large curve, red line)
Hello, my name is Eric Fedders. I am a Masters student at the University of Kansas. I am doing a study on organizations and buildings that increase social relationships and builds community. I am wondering if I can ask you a few questions about your organization for some data on my study. I am interested in a range of topics. For example, the number of members, opportunities for members to meet and work together, but also, the number of full-time and part-time employees, how old your organization is, how old the building is. With that in mind, would you mind just telling me a little bit about your organization first?

1. What year did your organization begin?

Members
Next, I would like to ask you a few questions about membership within your organization. This will tell me a little bit about who uses the building.

2. Do you have a membership program?
   a. If so, how many people are part of that number?

3. Outside of the member numbers, how many people visit your site each year?

4. Generally, have those numbers increased, decreased, or remained constant over the last five years?

5. Do members have the opportunity to join a smaller group or subset of people within the community?

Organization Structure
Next, I am going to ask some questions about how the organization is run and structured. This will help me get a handle on how communication is passed to members and how leaders run the organization.

6. How is the leadership structured? Is there a board of directors, for example?

7. How are those leadership roles filled?

8. What percentage of employees are paid (vs. volunteer)?

9. How do full time employees interact with the community? Are there structured relationships or activities? Do these rely on funding from your organization?

10. How do you communicate with your members, an email list for example?

Events
Next, I would like to know a little bit about what goes on within the organization. These questions will help me gauge what leaders and members are doing together, as well as in the surrounding community.

11. What are the regular events offered, and how often do those occur?

12. Are there events offered for members only?

13. Does your organization participate in or lead any community outreach programs, or programs specifically meant to draw in new people?

14. What type of programs do you invest in in the community? Would these programs be able to continue (or be hindered) if income was suspended?
Disaster
The goal of my research is to make organizations like yours more important in the recovery process after a disaster. For the final set of questions, I want you to imagine a natural disaster (like flooding or tornado) hitting Overland Park.

16. What year was the building you meet in constructed/opened?
   a. Was the building specifically created for your organization? Or repurposed later?

17. In the event of a disaster (such as a tornado), has your organization made preparations to enable your building to function as an emergency shelter?

18. What about a distribution center for food, clothing, or recovery information?

19. In the case of your building being severely damaged, where would money for repairs come from – government funding, patron donations, your leadership organization, or some combination thereof?

20. Does your organization have any experience in serving as first-responders after a disaster?

Building Components
The last set of questions is in regards to the building you meet in. I would just like to know if you building has any of the following components. Having any of these would increase the building’s capability for serving as an emergency shelter or distribution center after a disaster.

21. Kitchen?

22. Bathroom with showers?

23. Multi-use room?

24. Small rooms?

25. Storage area?

26. Backup generator?
Appendix F: Reasoning & Assumptions for Community Building Index Values

**Single-Family Home**
- Couple with 2 children in relatively new home
  - Visitors – people who come to the home that are not part of the immediate family/house residents; houseguests, parties hosted, and family visiting, averaging about 20 per month
  - Members – the number of people who reside in the home, 2 parents with 2 children
  - Membership change – change in number of family, but change is rare (birth/death only), so assume that for a household this will be constant
  - Small group – N/A
  - Organization age – N/A
  - Leadership group – N/A
  - Leadership group style – N/A
  -Events-Regular – N/A
  - Events-Community – N/A
  - Employees – N/A
  - Communication – N/A
  - General funding – N/A
  - Previous Disaster experience – N/A
  - Building year construction – year of home construction; assume 2000
  - Renovations – any significant renovations to the structure or code updates; assume no
  - Alternative options – is there anywhere else for the family to stay; assume yes, most could live with neighbors/ family members/hotels/etc.
  - Post-disaster programs – N/A
  - Location-Community – is the home central to the neighborhood/community; assume yes for young couple
  - Porch – assume yes
  - Sidewalk/lawn – assume yes
  - Emergency shelter – has the family prepared their home for use as emergency shelter? assume no
  - Kitchen – yes
  - Multi-purpose room – is there a room that could hold a significant number of people? assume no
  - Small rooms/offices – yes (bedrooms)
  - Storage area – assume yes (garage, shed, attic, etc.)
  - Bathrooms w/ showers – yes
  - Backup generator – assume no

- A couple with 4 children, older home
  - Visitors – people who come to the home not part of the immediate family/house residents; houseguests, parties hosted, and family visiting, averaging about 40 per month (more than last, children friends)
  - Members – the number of people who reside in the home, 2 parents with 4 children
  - Membership change – see above; constant
  - Small group – N/A
  - Organization age – N/A
  - Leadership group – N/A
  - Leadership group style – N/A
  - Events-Regular – N/A
  - Events-Community – N/A
  - Employees – N/A
  - Communication – N/A
  - General funding – N/A
  - Previous Disaster experience – N/A
  - Building year construction – year of home construction; assume 1980
  - Renovations – any significant renovations to the structure or code updates; assume no
  - Alternative options – is there anywhere else for the family to stay; assume yes, most could live with neighbors/ family members/hotels/etc.
  - Post-disaster programs – N/A
  - Location-Community – is the home central to the neighborhood/community; assume yes for this family
An elderly couple, no children, new home
- Visitors – people who come to the home that are not part of the immediate family/house residents; houseguests or family come to visit; assume 10 per month (few visitors with few friends)
- Members – the number of people who reside in the home; 2 adults
- Membership change – see above; constant
- Small group – N/A
- Organization age – N/A
- Leadership group – N/A
- Leadership group style – N/A
- Events-Regular – N/A
- Events-Community – N/A
- Employees – N/A
- Communication – N/A
- General funding – N/A
- Previous Disaster experience – N/A

- Building year construction – year of home construction; assume duplex will have new construction
- Renovations – any significant renovations to the structure or code updates; assume no
- Alternative options – is there anywhere else for the family to stay; assume yes, most could live with neighbors/ family members/hotels/etc.
- Post-disaster programs – N/A
- Location-Community – is the home central to the neighborhood/community; assume yes for this couple
- Porch – assume yes
- Sidewalk/lawn – assume yes
- Emergency shelter – has the family prepared their home for use as emergency shelter? assume no
- Kitchen – yes
- Multi-purpose room – is there a room that could hold a significant number of people? assume no
- Small rooms/offices – yes (bedrooms)
- Storage area – assume yes (garage, shed, attic, etc.)
- Bathrooms w/ showers – yes
- Backup generator – assume no

A large family (couple with 5 children), living on an old farmhouse
- Visitors – people who come to the home that are not part of the immediate family/house residents; houseguests or family come to visit; assume 20 per month
- Members – the number of people who reside in the home; 2 adults, 5 kids
- Membership change – see above; constant
- Small group – N/A
- Organization age – N/A
- Leadership group – N/A
- Leadership group style – N/A
- Events-Regular – N/A
- Events-Community – N/A
- Employees – N/A
- Communication – N/A
- General funding – N/A
Appendix F: Reasoning & Assumptions for Community Building Index Values

- Previous Disaster experience – N/A
- Building year construction – year of home construction; assume farmhouse will be old construction
- Renovations – any significant renovations to the structure or code updates; assume no
- Alternative options – is there anywhere else for the family to stay; assume yes, most could live with neighbors/family members/hotels/etc.
- Post-disaster programs – N/A
- Location-Community – is the home central to the neighborhood/community; assume no, out in the country
- Porch – assume yes
- Sidewalk/lawn – assume yes
- Emergency shelter – has the family prepared their home for use as emergency shelter? assume no
- Kitchen – yes
- Multi-purpose room – is there a room that could hold a significant number of people? assume no
- Small rooms/offices – yes (bedrooms)
- Storage area – assume yes (garage, shed, attic, etc.)
- Bathrooms w/ showers – yes
- Backup generator – assume no

**Apartment**
- Assuming an apartment building with 8 total 2 bed/2 bath units, each apartment has 2 adults
  - Visitors – people who come to the home that are not part of the immediate family/house residents; houseguests or family come to visit; assume 10 per month (fewer visitors in an apartment) per unit
  - Members – the number of people who reside in the home; 2 adults per unit
  - Membership change – apartments have turnover, but the total number of users will not vary significantly
  - Small group – yes, each unit within the building will host a family
  - Organization age – age of the apartment complex not important here due to turnover to the apartment
  - Leadership group – leadership group is in place, through ownership of the complex/building
  - Leadership group style – leadership group would typically be full time for a large apartment complex
  - Events-Regular – N/A
  - Events-Community – N/A
  - Employees – some employees to manage tenants/leases
  - Communication – N/A
  - General funding – money for organization comes from rent/income
  - Previous Disaster experience – assume no
- Building year construction – age of building, assume 2000
- Renovations – assume yes, with more strict codes/requirements due to turnover
- Alternative options – yes, most could live with neighbors/family members/hotels/etc.
- Post-disaster programs – N/A
- Location-Community – would vary but most would be at a central location in the community
- Porch – most will have either a porch or patio
- Sidewalk/lawn – apartment units do not typically have their own lawn/sidewalk
- Emergency shelter – most families will not have prepared their home as a post-disaster shelter
- Kitchen – yes
- Multi-purpose room – is there a room capable of holding a large number of people? no
- Small rooms/offices – yes
- Storage area – storage area will be minimal in an apartment/already used by the resident
- Bathrooms w/ showers – yes
- Backup generator – assume no backup generator is present

**Mobile Home**
- Visitors – people who come to the home that are not part of the immediate family/house residents; houseguests or family come to visit; assume 10 per month (fewer visitors for a mobile home)
- Members – assuming home with 2 parents and 2 children
- Membership change – changes only with birth/death so constant membership
- Small group – N/A
Appendix F: Reasoning & Assumptions for Community Building Index Values

- Organization age – N/A
- Leadership group – N/A
- Leadership group style – N/A
- Events-Regular – N/A
- Events-Community – N/A
- Employees – N/A
- Communication – N/A
- General funding – N/A
- Previous Disaster experience – N/A

- Building year construction – assume mobile home with old construction, even a newer mobile home will not be high strength/performance in a hazard event
- Renovations – assume no renovations
- Alternative options – yes, most could live with neighbors/family members/hotels/etc.
- Post-disaster programs – N/A
- Location-Community – assume the home is located within an area/park with multiple mobile homes
- Porch – assume no porch
- Sidewalk/lawn – assume no lawn
- Emergency shelter – no, home is not capable of housing post-disaster
- Kitchen – yes
- Multi-purpose room – no, lack of size for a large room
- Small rooms/offices – assume no
- Storage area – assume no
- Bathrooms w/ showers – yes
- Backup generator – assume no

Hospital
- Large/new hospital, state of the art, using KU Health System Main Campus when applicable
  - Visitors – data taken from AHD.com, using # of patient days KU Health System Main Campus
  - Members – no members, all users would be visitors
  - Membership change – N/A
  - Small group – N/A
  - Organization age – began as independent hospital in 1998 but school has been around since 1905 (use 1905)
  - Leadership group – assume hospital has a board of directors and/or leadership team (KU Med)
  - Leadership group style – all appear to be full time jobs (see link above)
  - Events-Regular – N/A
  - Events-Community – community outreach list gives a few different events throughout the year at KU Med
  - Employees – nearly all jobs would be paid/hired (doctors, nurses) but some volunteer opportunities are available, assume 90% of jobs are paid
  - Communication – N/A
  - General funding – hospital is non-profit, relies on donations and giving, as well as income from operations
  - Previous Disaster experience – nothing found on their website

- Building year construction – construction for the current hospital building completed in 1978
- Renovations – none was found online, but assume it has been maintained/updated due to it being a hospital
- Alternative options – would patients be able to be taken care of at a different facility? Assume no due to the large number of bed, another hospital would likely be unable to take the number of patients
- Post-disaster programs – community events listed are outreach events so they would continue
- Location-Community – KU med is downtown
- Porch – per Google maps, no porch
- Sidewalk/lawn – per Google maps, no lawn
- Emergency shelter – it is already a critical facility, there will be plans/preparations in place for a disaster
- Kitchen – yes (cafeteria)
- Multi-purpose room – based on size/floor plan it seems that there would be a large room somewhere, with the school of nursing area as well
- Small rooms/offices – yes (patient rooms and doctor offices)
Appendix F: Reasoning & Assumptions for Community Building Index Values

- Smaller hospital, use Blue Valley Hospital for reference
  - Visitors – data taken from AHD.com, using # of patient days
  - Members – no members, all users would be visitors
  - Membership change – N/A
  - Small group – N/A
  - Organization age – began in 2010
  - Leadership group – three-person leadership staff, see link above
  - Leadership group style – all appear to be full time jobs, see link above
  - Events-Regular – N/A
  - Events-Community – none are listed on their website
  - Employees – no volunteer positions are listed, assume all positions are paid
  - Communication – N/A
  - General funding – no info on website, but assume hospital is funded by income/patient revenue
  - Previous Disaster experience – nothing found on their website
  - Building year construction – building constructed in 2006, see link above
  - Renovations – yes, building had significant additions/new specialties in 2010
  - Alternative options – would patients be able to be taken care of at a different facility? Assume yes for this hospital due to the lower number of patients, they could be taken to a different hospital
  - Post-disaster programs – N/A
  - Location-Community – Blue Valley hospital is downtown
  - Porch – per Google maps, no porch
  - Sidewalk/lawn – per Google maps, there is a lawn
  - Emergency shelter – it is already a critical facility, assume there will be preparations in place for a disaster
  - Kitchen – yes (cafeteria)
  - Multi-purpose room – no floor plan readily available, assume no due to smaller size of hospital
  - Small rooms/offices – yes (patient rooms and doctor offices)
  - Storage area – yes
  - Bathrooms w/ showers – yes
  - Backup generator – yes, due to it being a critical facility

Power Plant

- Visitors – no visitors
- Members – no members
- Membership change – no members, no change in members
- Small group – no members, so no smaller subsets of people
- Organization age – typically would be of a similar age to that of the town/city, so likely fairly old
- Leadership group – will have a leadership group/committee within the government itself
- Leadership group style – typically would be full-time jobs within the government
- Events-Regular – no specified events
- Events-Community – no specified events
- Employees – all employees of the power plant would be paid
- Communication – no members, no communication mechanism needed
- General funding – funded through the government/taxes
- Previous Disaster experience – no

- Building year construction – varies, most are probably older buildings
- Renovations – likely have been renovated because they are a critical facility
- Alternative options – no
- Post-disaster programs – no programs pre- or post-disaster
- Location-Community – typically are located away from the rest of the town/residential areas
- Porch – no
Appendix F: Reasoning & Assumptions for Community Building Index Values

Fire Station
- Visitors – no visitors
- Members – no members
- Membership change – no members, so no change in members
- Small group – no members, so no smaller subsets of people
- Organization age – typically would be of a similar age to that of the town/city, so likely fairly old
- Leadership group – fire chief, likely would report to government entities above him
- Leadership group style – full-time in large cities, could be volunteer in smaller towns
- Events-Regular – no specified events
- Events-Community – no specified events
- Employees – full-time in large cities, could be volunteer in smaller towns
- Communication – no members, no communication mechanism needed
- General funding – funded through the government/taxes
- Previous Disaster experience – yes, or at least dealing with dangerous/intense situations
- Building year construction – varies
- Renovations – varies
- Alternative options – unlikely, but a large city would have more fire stations; it would slow response time
- Post-disaster programs – no programs pre- or post-disaster
- Location-Community – typically are located nearby business/residential areas
- Porch – no
- Sidewalk/lawn – no
- Emergency shelter – unable to house people, so no
- Kitchen – yes
- Multi-purpose room – potentially the garage?
- Small rooms/offices – potentially, could have rooms for meetings/classes, chief offices
- Storage area – likely to have a shed/maintenance area
- Bathrooms w/ showers – likely to have locker rooms/showers
- Backup generator – yes, due to it being a critical facility/government building

Restaurant
- Visitors – used Chipotle Mexican Grill data, which shows around 700 people per day
- Members – assumed 65% of daily customers are enrolled in loyalty program (Loyalty Program stats)
- Membership change – assume membership rises as the use of internet/mobile rises (easier to use/sign up)
- Small group – members have no interaction with other members, so no
- Organization age – age of restaurant (if chain, use age chain) – Chipotle 1993
- Leadership group – yes, both management team and board of directors
- Leadership group style – full-time
- Events-Regular – no specified/regular events
- Events-Community – may do some time of outreach/community benefit sales/fundraisers
- Employees – all would be hired/full-time
- Communication – have email addresses, phone numbers, mobile app, active social media accounts
- General funding – funded through business income
- Previous Disaster experience – unlikely
- Building year construction – varies
- Renovations – varies
Appendix F: Reasoning & Assumptions for Community Building Index Values

- Alternative options – yes, many other restaurants nearby with kitchen/seating
- Post-disaster programs – no regular events, and outreach events would not continue
- Location-Community – typically are located nearby business/residential areas
- Porch – yes, either has a front entry way, could have outdoor patio/seating
- Sidewalk/lawn – no
- Emergency shelter – unable to house people, so no
- Kitchen – yes
- Multi-purpose room – yes, general seating area
- Small rooms/offices – no
- Storage area – no
- Bathrooms w/ showers – no
- Backup generator – will vary, but is unlikely

**Bowling Alley**

- Visitors – IBISWorld shows 269.2 million users in 2017, with 3,700 establishments
- Members – Bowling Industry Overview (Sandy Hansell) reported 2 million frequent bowlers at 4,100 alleys
- Membership change – Sandy Hansell and IBISWorld both show the industry as growing
- Small group – yes, different leagues meet on different nights, team bowling
- Organization age – age of bowling alley will vary, many are well-established
- Leadership group – no outside of the managers/owners
- Leadership group style – N/A
- Events-Regular – league bowling 4/5 meets nights per week
- Events-Community – very few, outside of maybe a few kids nights/fundraisers
- Employees – all would be hired/full-time
- Communication – have email addresses or phone numbers for members
- General funding – funded through business income
- Previous Disaster experience – unlikely
- Building year construction – varies
- Renovations – varies
- Alternative options – depends on city size, small town would only have 1, but larger city (like OP) has 2/3+
- Post-disaster programs – regular bowling league would not continue
- Location-Community – typically are located nearby business/residential areas
- Porch – unlikely to have outdoor porch
- Sidewalk/lawn – no
- Emergency shelter – unable to house people, so no
- Kitchen – yes
- Multi-purpose room – yes, general seating area
- Small rooms/offices – no
- Storage area – yes, could have locker storage or back rooms for storage
- Bathrooms w/ showers – no
- Backup generator – will vary, but is unlikely

**Shopping Mall**

- Visitors – calculated from this using US population 323.1 million, 75% of Americans visit per month at an average of 3.4 timers per person per month to 114,846 different shopping malls
- Members – assumed 65% of monthly customers are enrolled in loyalty program (Loyalty Program stats)
  - Divide monthly numbers by 3.4 (average visits per person per month) and multiply by 0.65
- Membership change – document referenced for visitors shows positive growth in mall purchasing/visits
- Small group – no, members likely only receive promotional materials
- Organization age – varies
- Leadership group – not a separate group outside of the owners/managers
- Leadership group style – N/A
- Events-Regular – no regular events
- Events-Community – very few, outside of maybe a few kids nights/fundraisers
- Employees – all would be hired/full-time
Appendix F: Reasoning & Assumptions for Community Building Index Values

- Communication – members would likely be enrolled in email list
- General funding – funded through business income
- Previous Disaster experience – unlikely

- Building year construction – varies
- Renovations – varies
- Alternative options – no, and tenants would all be sent to find their own alternative
- Post-disaster programs – no regular events, and outreach events would likely stop
- Location-Community – typically are located nearby business/residential areas
- Porch – no
- Sidewalk/lawn – no
- Emergency shelter – is possible but unlikely, as it is a large space central to the community
- Kitchen – yes (food courts)
- Multi-purpose room – yes, large hallways and stores
- Small rooms/offices – no, only the few offices, and small side-stores would not count
- Storage area – yes, likely a large one for the mall and many of the stores would have one as well
- Bathrooms w/ showers – no
- Backup generator – yes

Gas Station
- Visitors – NACS Report gives 40 million fill ups per day, 150,000 gas stations across the US
- Members – assume 65% of weekly customers are in loyalty program, assume people fill once per week
- Membership change – assume membership as constant
- Small group – no small groups, no interaction between members
- Organization age – age of gas station will vary
- Leadership group – no governing body outside of store managers
- Leadership group style – N/A
- Events-Regular – no regular events
- Events-Community – no outreach/community events
- Employees – all would be hired/full-time
- Communication – no interaction outside of the gas station
- General funding – funded through business income
- Previous Disaster experience – unlikely

- Building year construction – varies
- Renovations – varies
- Alternative options – many alternatives, often very close by
- Post-disaster programs – N/A
- Location-Community – typically are located nearby business/residential areas
- Porch – no
- Sidewalk/lawn – no
- Emergency shelter – unable to house people, so no
- Kitchen – yes
- Multi-purpose room – no
- Small rooms/offices – no
- Storage area – yes, will have area to store convenience store items
- Bathrooms w/ showers – most will not
- Backup generator – varies, but assume that it will

Grocery Store
- Visitors – Credit Donkey references 32 million adult shoppers per day at 38,000 grocery stores
- Members – assume 65% of weekly customers, link above reference average is 1.5 trips per week
- Membership change – assume membership as constant
- Small group – no small groups, no interaction between members
- Organization age – varies
- Leadership group – no governing body outside of store managers
Appendix F: Reasoning & Assumptions for Community Building Index Values

- Leadership group style – N/A
- Events-Regular – no regular events
- Events-Community – might have kids days, fundraisers, things of that nature
- Employees – all would be hired/full-time
- Communication – members would be on an email list about sales/discounts
- General funding – funded through business income
- Previous Disaster experience – unlikely
- Building year construction – varies
- Renovations – varies
- Alternative options – typically there are multiple grocery stores in a town
- Post-disaster programs – N/A
- Location-Community – typically are located nearby business/residential areas
- Porch – no
- Sidewalk/lawn – no
- Emergency shelter – unable to house people, so no
- Kitchen – yes
- Multi-purpose room – yes, store floor could be converted by moving shelves
- Small rooms/offices – no
- Storage area – yes, will have area to store shelved items
- Bathrooms w/ showers – no
- Backup generator – varies, but assume that it will

Factory

- Visitors – no visitors
- Members – no members outside of the employees
- Membership change – N/A
- Small group – no members, no small groups
- Organization age – age of business/factory will vary
- Leadership group – no governing body outside of store managers/owners
- Leadership group style – N/A
- Events-Regular – no regular events
- Events-Community – no outreach/community events
- Employees – all would be hired/full-time
- Communication – no members, no need for communication
- General funding – funded through business income
- Previous Disaster experience – unlikely
- Building year construction – varies
- Renovations – varies
- Alternative options – typically there are multiple grocery stores in a town
- Post-disaster programs – N/A
- Location-Community – typically are located nearby business/residential areas
- Porch – no
- Sidewalk/lawn – no
- Emergency shelter – unable to house people, so no
- Kitchen – yes
- Multi-purpose room – yes, store floor could be converted by moving shelves
- Small rooms/offices – yes, for engineers/office workers
- Storage area – yes, will have area to store product or other items
- Bathrooms w/ showers – no
- Backup generator – varies, but assume that it will

High School

- Visitors – no visitors outside of students
- Members – members will be the students, 2011 report gives average Kansas high school size of 415 students
Appendix F: Reasoning & Assumptions for Community Building Index Values

- Membership change – assume constant (2001 report has average of 405 students)
- Small group – yes, each grade is a smaller group, and each class is smaller yet
- Organization age – school age will vary, most are well-established
- Leadership group – yes, will have a board of directors/trustees, public schools through government
- Leadership group style – board of directors/trustees as part-time/volunteer requirements, government FT
- Events-Regular – school five days per week
- Events-Community – many different clubs, extra-curricular activities, sports events
- Employees – high school would be all hired/full-time, elementary schools may have volunteers help
- Communication – yes, through email mostly
- General funding – public schools through government/taxes, private through donations and income
- Previous Disaster experience – unlikely

- Building year construction – varies
- Renovations – varies
- Alternative options – no alternatives would be able to house all of the students
- Post-disaster programs – school and any extra-curricular activities would stop
- Location-Community – typically located in residential areas or central to the community
- Porch – no
- Sidewalk/lawn – yes
- Emergency shelter – due to it being a large structure, it could have been discussed
- Kitchen – yes
- Multi-purpose room – yes (gym, cafeteria)
- Small rooms/offices – yes (classrooms, offices)
- Storage area – yes
- Bathrooms w/ showers – yes (locker rooms)
- Backup generator – varies, but assume that it will

Office Building

- Visitors – no visitors outside of employees
- Members – Average office building size and workers per square foot give 100 workers per office building
- Membership change – assume constant
- Small group – yes if office building houses multiple companies, no if it is a single company
- Organization age – will vary based on age of company/organization
- Leadership group – no special leadership group beside executives/owners
- Leadership group style – leaders would be full-time employees
- Events-Regular – work five days per week
- Events-Community – no outreach events
- Employees – all employees would be hired/full-time employees
- Communication – yes, through email mostly
- General funding – company is funded by business income (non-profit would be through donations)
- Previous Disaster experience – unlikely

- Building year construction – varies
- Renovations – varies
- Alternative options – yes, a smaller firm could relocate entirely, work could be done from home
- Post-disaster programs – work would likely continue from another location
- Location-Community – varies, could be at a downtown/central location or a business district
- Porch – no
- Sidewalk/lawn – no
- Emergency shelter – unlikely to have been discussed
- Kitchen – no besides a small breakroom
- Multi-purpose room – no
- Small rooms/offices – yes
- Storage area – yes, likely a room for extra files, or an extra office
- Bathrooms w/ showers – no
- Backup generator – varies but unlikely, large office space (high-rise) would be more likely