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Resilient and Sustainable Infrastructure Systems: The Role of Coordination, Stakeholder Participation, and Training in Post-Disaster Reconstruction

Aaron Opdyke, University of Colorado Boulder, USA
Amy Javernick-Will, University of Colorado Boulder, USA

Proceedings Editors
Paul Chan, The University of Manchester and Robert Leicht, The Pennsylvania State University

RESILIENT AND SUSTAINABLE INFRASTRUCTURE SYSTEMS: THE ROLE OF COORDINATION, STAKEHOLDER PARTICPATION, AND TRAINING IN POST-DISASTER RECONSTRUCTION

Aaron Opdyke,[1] Amy Javernick-Will[2]

ABSTRACT

This early concept research outlines the need to better understand reconstruction processes in post-disaster environments that can create resilient and sustainable infrastructure systems and proposes methodology aimed at addressing gaps in theory and practice. The paper first introduces the rationale for studying project outcomes of sustainability and resilience and proposes a new method to conceptualize resilience through a network perspective. Next, the paper reviews literature on three factors – coordination, stakeholder participation, and training – each of which is posited to influence these project outcomes. After research questions are identified, the paper proposes research methodology that will study coordination, participation, and training across phases of infrastructure reconstruction from a network perspective in the Central Visayas region in the Philippines. In addition to analyzing the influence of each of these factors individually on the project outcomes, fuzzy set qualitative comparative analysis (fsQCA) is proposed as a novel means of capturing snapshots of project phases and analyzing pathways that navigate the complexity of post-disaster reconstruction.

KEYWORDS: Resilience, Sustainability, Post-Disaster Reconstruction

INTRODUCTION

Disaster events, and their effects, continue to affect millions of people annually (Guha-Sapir et al. 2013). These disaster events often devastate infrastructure in communities, creating a pressing need to reconstruct infrastructure systems under severe time constraints and with limited funds from a diverse group of agencies and organizations. To reconstruct damaged infrastructure that has long-term functionality, communities must mobilize and coordinate resources and knowledge from government agencies, organizations, and communities. While coordination, participation and training are difficult in 'normal' conditions, post-disaster environments are inherently complex, and place additional stress on social and organizational networks and economic systems, in addition to infrastructure systems, resulting in the needed application of vastly different construction procedures to meet these demands.

In practice, there is often a failure to address pre-disaster vulnerabilities in the reconstruction of infrastructure. The case of the 2004 Indian Ocean tsunami is a prime example, where in Aceh, Indonesia organizations did little to solve underlying problems in the housing sector, rebuilding homes from masonry, a poor choice for seismic performance (Kennedy et al. 2008). To make matter worse, there was no unified approach to housing – many organizations focused solely on temporary housing with no regard as to how this would affect the eventual transition to permanent housing – a clear lack of coordination. In addition, past work found that even when permanent housing was constructed, a lack of coordination between NGOs constructing shelter in communities led to different housing structures and resources provided to

[1] PhD Student, University of Colorado Boulder, aaron.opdyke@colrado.edu
[2] Assistant Professor, University of Colorado Boulder, amy.javernick@colorado.edu

different members of a community, contributing to non-integrated infrastructure systems, social tensions, and community unrest (Jordan and Javernick-Will 2013b).

While coordination, participation and training appear important for long term functionality of infrastructure systems, little is known about what processes facilitate this work. As a result, this early concept paper outlines methodology to investigate post-disaster construction delivery mechanisms to better understand what reconstruction processes and stakeholder networks help create resilient and sustainable infrastructure systems in post-disaster environments. Specifically, this research will identify the *processes* that are employed and the *networks* formed to mobilize resources and coordinate work in various rebuilding phases, including *planning, design, construction, and operation & maintenance*. We will map these processes and networks throughout rebuilding phases and compare and contrast these processes across multiple projects and communities, to determine *how* these processes influence the resilience and sustainability of built infrastructure and social systems, and what process and network *pathways* lead to resilient and sustainable infrastructure systems.

POINTS OF DEPARTURE

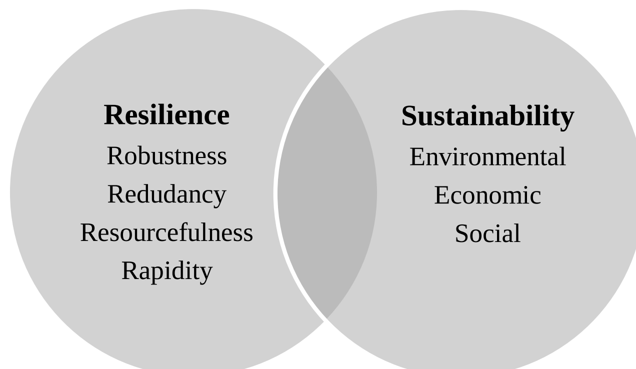

Figure 1: Conceptualization of Resilience and Sustainability

Earlier work by Jordan and Javernick-Will (2013b) retrospectively analyzed how combinations of pre-disaster community factors and post-disaster strategies influenced various types of recovery – economic, social, infrastructure – seven years after a disaster event. From this research, post-disaster strategies such as recovery agency embeddedness, construction oversight, training, community participation, and coordination emerged as important for recovery (Jordan 2013). However, these factors need to be further unpacked, and it appears that coordination and participation over time are important for the long-term functionality and use of infrastructure projects in a community. Because data was collected for the cases analyzed in India and Sri Lanka seven to nine years post-disaster event, only retrospective data was collected and information on the coordination and participation structures and processes that were employed, as well as how they developed over time, was difficult to obtain due to fading memories and lost documentation. As a result, this study deviates from past work by focusing specifically on components of recovery – resilience and sustainability of infrastructure systems – and analyzing critical post-disaster strategies (coordination, stakeholder participation and training) across project phases from the recent Super Typhoon Haiyan in the Philippines.

Resilience and Sustainability of Infrastructure Systems

This research seeks to improve two post-disaster outcomes – resilience and sustainability – of built infrastructure. While definitions of resilience often fail to separate sustainability as a unique outcome, this research distinguishes between the two to build on literature which calls for a differentiated approach (Bocchini et al. 2013; Hassler and Kohler 2014). We define *resilience* in terms of adaptive capacities that support system functionality in times of crisis or stress (Pooley et al. 2006); and *sustainability*, in contrast, will focus on capacities that prevent system degradation and maintain a system equilibrium (López-Ridaura et al. 2005).

Resilience

Definitions of resilience are often diverse due to disciplinary boundaries and there is lacking widespread interdisciplinary consensus; however, the disaster literature does converge on two characteristic points: resilience is conceptualized as a set of abilities or capacities and it is better explained as adaptability over stability (Norris et al. 2007). Further, resilience can be characterized by four properties: *robustness, redundancy, resourcefulness, and rapidity* (Bruneau et al. 2003). Conventional approaches to project outcomes focus on resources and structures (Lee Ann and Knoepfel 2014), however, there is a pressing need to understand resilience from a process perspective. Past work has extensively studied the role of social capacities in resilience at the community level (Aldrich 2012; Cutter et al. 2008), however less is known about how societal mechanisms support (or deter) infrastructure resilience. Physical models of resilience have also been well studied (Vugrin et al. 2010) but these efforts focus almost exclusively on the design phase, neglecting the role that construction and operation & maintenance phases play in ensuring system resilience. There are, however, increasing efforts to link these and consider infrastructure as socio-technical systems (Holnagel 2014), whose functioning more accurately describes the concept of resilience. The literature also neglects the planning phase *after* a disaster, with most studies focusing on pre-disaster planning (Tobin 1999).

Sustainability

The second outcome of this study, sustainability, possesses a range of connotations, often tailored to specific industries and sectors. Definitions focus on three primary aspects of sustainability – economical, environmental, and social – with a growing number of indicators for each area (El-Anwar et al. 2009; Shen et al. 2010). Recent literature emphasizes the importance of the last component, social sustainability, in both the design, construction, and operations and maintenance phases (Kaminsky and Javernick-Will 2013; Valdes-Vasquez and Klotz 2013). Fundamentally, this study will hone on a definition of capacities that promote continued use and functionality of infrastructure.

We will approach our understanding of resilience and sustainability as two unique outcomes, but will also analyze a third outcome, which encompasses both together. For example, consider a water distribution system that has a central governing body that collects usage fees and has a track record of excellent maintenance. In addition to other characteristics, we might consider this system sustainable. This same system may lack resilience if procedures are not in place to keep the governing body operating in times of crisis should key organizational staff be displaced or unable to work following a disaster. Sustainability and resilience may encompass the same system components, however each is comprised of differing qualities. Operationalizing each outcome will provide insight as to the processes needed over time to obtain these coveted goals.

FACTORS POSITED TO AFFECT RESILIENCE AND SUSTAINBILITY

As indicated earlier, our past research has suggested a strong connection between the engineering and construction delivery *process*, eventual recovery, and risk mitigation (Jordan and Javernick-Will 2013a; Pheng et al. 2006; Ofori 2002). From this work, we hypothesize that different post-disaster strategies for **coordination, stakeholder participation, and training** in each of the **infrastructure project delivery phases** of *planning, design, construction, and operations & maintenance* influence resilience and sustainability of infrastructure systems. Recently, agencies have encouraged strategies such as community participation in the design and construction process; however, emerging research has highlighted our limited understanding of these interventions. For instance, design decisions extracted through community participation were shown to decrease long-term maintenance (Khwaja 2004). Unpacking this example, and the aforementioned factors, to create and calibrate constructs for cross-case analysis will enable us to better understand successful (and unsuccessful) strategies.

Coordination

Early literature defined coordination as “the orderly arrangement of group effort, to provide unity of action in the pursuit of a common purpose” (Mooney 1947, pg. 5). Lindblom suggests that coordination is the systematic relationship between decisions (Lindblom 1965). Others, such as Malone, propose coordination as “the *process* of managing dependencies among activities,” placing emphasis on the space where organizational activities relate (Malone and Crowston 1994). Organizations are grounded in individualistic goals that often conflict in the face of inter-organizational partnering (Shapira 2002). Aligning these parties becomes a paramount task in coordination efforts in post-disaster environments that impose immense stress and time constraints on organizational tasks, compounding alignment difficulties (Comfort and Kapucu 2006).

Research has highlighted that poor coordination in large-scale disasters, such as the 2010 Haiti earthquake, result in deficiencies in recovery service provision (Ritchie and Tierney 2011). The need to align and coordinate organizations when a disaster or crisis occurs is obvious: independent actions of one organization without consideration of the impact on other sectors can have severe negative consequences. Researchers have documented that coordination improves the recovery process (Chen et al. 2008; Le Masurier et al. 2006), but not *how* the planning and structuring occurs. In addition, there is little acknowledgement, let alone study, that different types of coordination emerge (e.g. local, region, national) that have different characteristics. Further, the evolutionary nature of organizational coordination networks has been neglected. There is a need to understand dynamic coordination in a pressured, temporal context. In these situations, strategies that are applicable during planning phases may not translate into later reconstruction phases where organizational demands differ.

As a result, there is a clear need to better understand these types of coordination, their characteristics, and their evolution over time to better understand the influence of coordination on recovery. This research proposes to unpack coordination, investigate coordination throughout project phases, and compare and contrast coordination across projects and communities to determine what coordination strategies enable sustainable and resilient infrastructure.

Stakeholder Participation

Prevalent in the disaster literature, community participation is frequently cited as an important intervention to achieve recovery (Lawther 2009; Maskrey 1989). There is, however, a lack of consensus on what is meant by ‘participation’ – some suggest that the term is left intentionally ambivalent and definitionally vague to enable political agency and maintain relations of rule (Cornwall and Brock 2005). As a result, the success of participatory methods are contentious, and, in an industry consumed with measuring success and failure, the cornerstone of modern development – participation – is a moving target.

One contentious point is whether participation is a ‘means’ or an ‘end’ (Parfitt 2004). As a *process,* participation looks materially different than under the light of an *objective*. Used as a process, participation is characterized by a desire to work within existing local structures and fit within culturally acceptable practices to achieve operational and project efficiency goals. In contrast, participation as an objective seeks to promote equality in a population through changes to political, economic, and cultural structures. Each form of participation has its advantages, but are radically different in *how* they exist. In this proposed research, we will focus on the use of participation as a process. This is not to discount its use as an objective, rather we include this as an enabling factor of the outcomes of this research – resilience and sustainability.

One of the most comprehensive frameworks of participation to date stems from Cohen and Uphoff (1980). They suggest four kinds of participation: (1) *decision-making*; (2) *implementation*; (3) *benefits*; and (4) *evaluation*. In addition to kinds of participation, Cohen and Uphoff also suggest *who* is involved and *how* participation occurs are important aspects to consider. The literature documents decision-making and benefits well (Hayward et al. 2004; Mohanty 2004; Oakley 1991), however, implementation and evaluation are less prevalent and there is little work to date that analyzes how all types of participation interact to form a comprehensive system. Early work in this systems approach has been started by Johnson et al. (2006), however it often remains intra-sectorial and there is need to expand the system to encompass multiple sectors.

Traditionally, participation is viewed as community members having a ‘voice’ in decision making (Williams 2004). This view of participation focuses solely on political governance, neglecting a resource-focused perspective. As a result, the context of *how* a project will occur through financial, labor, and material contributions, is largely ignored, but may be much more important in the disaster context. This can become particularly important when considering multiple entities’ goals, such as donor driven requirements, and their eventual effect on project performance (Chang et al. 2011). Trends for participatory methods now commonly use ‘participation’ as a means to incorporate ‘local knowledge’ in the implementation of solutions, viewing local knowledge as a tangible object that can be extracted (Mosse 2001), with a lack of consideration that ‘people’s knowledge’ is actually formed through the planning *process*. Cooke and Kothari (2001) outline several flaws of current participation literature, including (1) the lack of consideration and appropriate valuation of the time, energy, and resources of local populations in participatory techniques; (2) the failure to represent all sectors of a population; and (3) the lack of translation from involvement into empowerment. Each of these points has potentially dramatic consequences in the disaster context and requires additional study to understand their role in the rebuilding process.

Training

There has been increasing attention to involve multiple stakeholders in the post-disaster reconstruction process, however it is important for these parties to possess fundamental skills in the tasks they are performing. Reconstruction often involves the incorporation of new building techniques that aim to reduce pre-disaster vulnerabilities, requiring governments, designers, construction workers, and community members to acquire new knowledge. This is no easy task considering the range of educational and socio-economic backgrounds of these parties. The training of the former of these, design and construction professionals, has been well studied and knowledge management frameworks for these individuals have been proposed (Amaratunga and Haigh 2011; Haigh et al. 2006). The later, construction trades and community members lacks the attention other stakeholders have received and further study is needed. Training is a critical step in transferring knowledge to stakeholders, not only in participatory processes of design and construction, but also to build capacity to enable community members to operate and maintain infrastructure systems in a self-sufficient manner. Past work in the disaster field has focused on the training of first responders (Paton 1994), however there is a dearth of research on post-disaster strategies. Most work to date remains broad on general cognitive skills (Merriënboer 1997) and does not distinguish the processes of engineering and construction tools (e.g. 2-D plans, 3-D models, hands-on workshops).

Types of training are generally grouped into two categories – on-the-job and off-the-job (Tabassi and Bakar 2009). On-site training for a construction labor workforce commonly utilizes an apprenticeship model to provide hands-on experience to learners. Problem solving skills are typically taught in a contextual manner and arise from interactions within the work environment. In contrast, off-the-job training is commonly associated with classroom lectures, film, and simulation exercises. This type of training abstracts concepts in an attempt to make knowledge generally applicable across multiple situations. Past work has highlighted that frequent communication between technical staff and the labor force is essential (Brebbia and Chon 2012), however there remain gaps. Specifically, calls in the literature highlight the need to study the *effectiveness* of training programs (Wang et al. 2008).

Another component that is important to consider in developing countries is in what context the training is administered. Formal trainings that are organized and systematic may have differing levels of knowledge transfer than informal methods. The differences between these two is recognized (Jayawardane and Gunawardena 1998), but the levels of effectiveness has not been studied. Durations of training are another aspect that has gone unstudied that are critical to understand effectiveness of programs.

RESEARCH METHODS

This research will study coordination, stakeholder participation, and training throughout post-disaster planning, design, construction and operations & maintenance in the context of the recent natural disaster, Super Typhoon Haiyan, described below. We will conduct the proposed research via a three-phase, mixed methods approach. Data collection will gather information on coordination, stakeholder participation and training efforts using a quasi-longitudinal research approach at four points-in-time: planning, design, construction, and operations & maintenance. Using this data, we will perform a cross-case analysis using fuzzy-set qualitative comparative analysis (fsQCA) to determine reconstruction strategies, combined or in isolation, that aid sustainability and resilience built infrastructure.

Research Setting: 2013 Super Typhoon Haiyan

On November 8, 2013, Super Typhoon Haiyan made landfall in Guiuan in the Eastern Samar province of the Philippines. The storm sustained wind speeds of 196 mph and gusts of up to 235 mph, making it the fourth most intense tropical cyclone ever observed and the strongest to ever make landfall (Masters 2013). Over 16 million people were affected by the disaster, with the Philippian government reporting 6,201 confirmed deaths and 28,626 injured as of January 29 with numbers continuing to rise (Del Rosario 2014). Infrastructure was severely damaged in multiple sectors. Over four million people were displaced from their homes and more than 1.1 million homes were damaged, half of these completely destroyed. An initial UNICEF rapid assessment estimated that 80 to 90 percent of schools in Aklan, Capiz and Iloilo provinces (Western Visayas region) were partially or completely damaged. Furthermore, up to forty percent of medical facilities were not functioning in some regions. The islands of Leyte and Samar sustained the most damage – Tacloban City, Leyte’s largest urban center, reported 90 percent of infrastructure destroyed (CFE 2014).

Before Haiyan made landfall, legislation set the stage for response to the disaster. In 2010, the Philippian Senate and House of Representatives passed Republic Act No. 10121, legislation that created the National Disaster Risk Reduction and Management Council (NDRRMC) (Guingona III and Bizaon 2009). While this government entity was tasked with reducing disaster risk, managing the relief and recovery process for national disasters, and serving as the central governing body to coordinate disaster efforts; it appears that the agency failed to step up to its role of central coordination before, during, and after the event (Legaspi 2013). In wake of this, a decentralized model has been proposed to coordinate disaster response and build the capacity of local governments. In addition to NDRRMC, several key organizations have entered the Philippines to provide recovery services. Aside from multi-lateral organizations such as UNICEF, UN-OCHA, WHO and others, significant support is being provided by the US government and US-based organizations. To date, the US government has provided over $86 million in support through the US Agency for International Development (USAID) and Department of Defense (USAID 2014). The cluster system previously established by the United Nations Office for Coordination of Humanitarian Affairs (UN-OCHA) appeared to be the dominant coordinating organization in the early stages.

Community and Project Selection

An embedded unit of analysis of a project within a community will be used to analyze sustainability and resilience outcomes. The communities will represent larger cases, whose stakeholders include government officials, NGO's, other aid agencies, and community members. Those involved in supplying funding, expertise, resources, use, or maintenance of the constructed infrastructure will represent the bounded system of the case (Creswell 2012; Stake 1995). To identify these communities, we will look for communities of a comparable size, but that display variation in the number of reconstruction agencies, how they coordinate, and the recovery processes they intend to use to 'theoretically sample' cases for in-depth study (Eisenhardt and Graebner 2007; Flyvbjerg 2006). We plan to select twelve communities based upon the above criteria with six from Region VI (Western Visayas) and six from Region VIII (Eastern Visayas). We select six from the Eastern Region because a magnitude 7.2 earthquake, centered in Bohol, struck one month before Haiyan, killing 222 people and damaging over 73,000 homes (Del Rosario 2013). This will help us to isolate Haiyan while considering the impact of multiple, subsequent disasters on infrastructure reconstruction efforts.

Analyzing Coordination, Stakeholder Participation, and Training over Project Phases

Once the communities are identified, we will identify reconstruction projects (e.g., shelter, water, sanitation, roads, electricity) and stakeholders involved in each project within the community. This will allow us to bound our analysis within the community and collect qualitative and quantitative data in the form of documents, archival records, semi-structured interviews, participant-observations, physical artifacts and audio-visual materials on coordination, stakeholder participation, and training. This will enable us to capture real-time interactions of coordination and training, which will enhance our ability to analyze *actual* processes and compare and contrast this with documented procedures. We will interview organizational staff and community stakeholders at different project stages capturing each construct at that specific point in time. We recognize that it may not always be possible to capture distinct phase data due to overlapping project phases. Similarly, some data may need to be collected retroactively. In these cases, we will ask research subjects how their perceptions changed and validate these answers through multiple staff members within a single organization. Additionally, documentation and other artifacts will be collected during each project phase. Combining and analyzing multiple types of data helps to confirm and validate processes and networks through triangulation (Corbin and Strauss 2008; Eisenhardt 1989; Yin 2009). Interviews will be conducted in the local language specific to the region (Cebuano, Tagalog, or Waray) and translated to English.

Data Collection

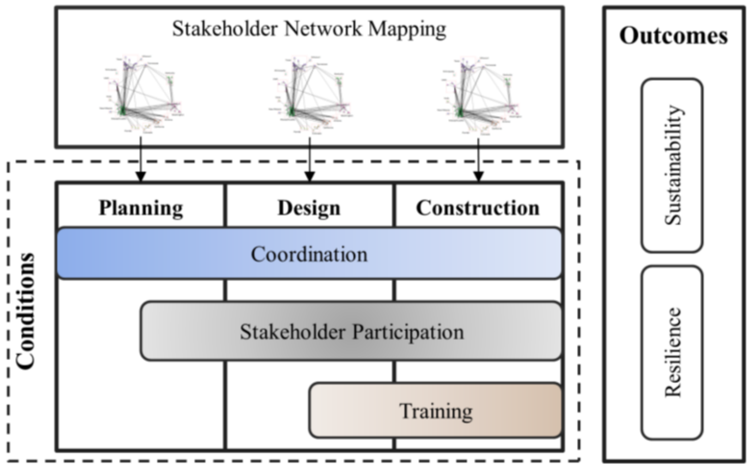

Figure 2: Data Collection Overview

To determine ***Coordination***, interview questions will ask who is coordinating with whom, what project elements they are coordinating, and what information is being transferred when and at what frequency. In addition, due to our quasi-longitudinal analysis, we will be able to pinpoint tensions that arose, how these tensions were overcome, and how this affected network structure. We will also investigate their infrastructure reconstruction goals and reporting requirements (e.g., donor reporting requirements for NGO's). This data will help with the explanatory analysis approach to determine how goals and potential conflicts affected the structuring of coordination efforts among organizations, agencies, and community-based groups. Existing processes and procedures, planned organizational structures, and stated goals will be collected and analyzed and all data will be informed with on-the-ground observation by the research team.

Furthermore, we will obtain attribute information on each stakeholder (community, organization, or agency), including each stakeholder's previous experience in the community, region, or country (their 'level of embeddedness'); previous experience in post-disaster environments and with the type of infrastructure they are reconstructing; and dyadic information on the previous experience with other reconstruction agencies. Analysis of this condition will be used in combination with other phases to determine if the level of experience along various factors affects post-disaster construction processes.

To determine ***Stakeholder Participation***, interview questions will ask all stakeholders to describe their roles in infrastructure planning, design, construction, and operations & maintenance, including the information and resources that they provided and received in this role (e.g., financial contributions, labor, knowledge), when they occupied different roles (e.g., shelter selection, design, construction), and the process of soliciting and gaining reciprocal participation (e.g., speeches at collective community meetings, open discussions).

To determine ***Training***, we will observe any training sessions, collect information distributed to community stakeholders (e.g. pamphlets, manuals), and ask organizations and agencies to describe the training procedures they implemented in the field. We will attend to the process used for training, whether information was communicated in a uni- or bi-directional fashion, the degree of tacitness of knowledge transfer (e.g., pamphlet or in-person, experiential training session), and the degree of visualization used (e.g., 2-D plans, 3-D computer models, 3-D printed models).

The desired outcomes of this study—***sustainable infrastructure*** and ***resilient infrastructure***—will be determined in two separate components. We will operationalize resilience through a network perspective in two central areas: **physical systems** and **societal systems**. Data collection on resilience outcomes will be collected during the operation & maintenance phase. Each pillar of resilience discussed previously will be characterized by a network metric (e.g. size and reach of network for robustness; duplicate ties for redundancy; diversity of network for resourcefulness; and proximity for rapidity). We will observe and document the service an infrastructure provides, its location, operability and existing condition, and connections to other infrastructure (e.g. houses connected by electrical grid). Physical resilience will be measured by quantifying interactions within the larger infrastructure system present, relying on the network metrics mentioned above. The second component of resilience, societal systems, will measure organizational, institutional, and community characteristics that support the adaptive nature of infrastructure.

We will operationalize system sustainability through an index that is composed of indicators in three areas – **economic, environmental, and social**. We will adapt indicators and weighting from the past work of Ugwu and Haupt (2007) who have developed indicators specific to developing countries. For economic indicators we will examine whether the infrastructure is affordable for a given population and whether they have the monetary means to maintain and repair the system (eg. initial cost, life cycle cost, and average income). Environmental factors will probe at the disruptance of natural resources (e.g. sourcing of construction materials). Finally, social sustainability will collect data on cultural factors that promote or inhibit use and maintenance.

Analysis

The qualitative data will be transcribed and imported into coding software for content analysis. The initial coding will focus on the macro-categories of *Coordination*, *Stakeholder Participation* and *Training* across the project phases of *Planning*, *Design*, *Construction* phases. In addition, we will collect and analyze data for the outcomes, *Sustainability* and *Resilience*, *in* the *Operations and Maintenance* phase.

In addition to content analysis, we will assemble sociometric data matrices and networks for coordination, participation, and training at each distinct project phase. The data will be analyzed for each community at each phase using sociometric network visualizations and calculations. We will also analyze network emergence as this will help us identify structural changes and identify why they occurred through the qualitative data collected through interviews and observations to help determine what influenced the network formation.

"Pathways" to Sustainable and Resilient Infrastructure

Our final component of analysis will employ fsQCA, to analyze what coordination, participation and training strategies, in combination or isolation, enable resiliency, what factors lead to sustainable infrastructure, and what factors lead to both. While traditional case study analysis helps understand the complexities of disaster recovery, it is difficult to generalize from such studies (Chang 2010). In fsQCA, an outcome of interest is identified – in this case, sustainable and resilient infrastructure – and data is collected for conditions posited to affect that outcome – in this case, coordination, stakeholder participation, and training, at different project phases. This research methodology is well-suited to analyze the disaster context due to the complexity and interdependence of actions and strategies under study.

This methodology builds on the past work in the disaster field that has employed fsQCA (Jordan et al. 2011). Using an embedded unit of analysis of a project within a community, the qualitative and quantitative data collected will be calibrated for each condition and outcome. Each condition is scored with values between 0 and 1, where a score of 1 represents full membership in a set and a score of 0 represents full non-membership. Typically, values are calibrated in-directly through a crisp set, 4- or 6-value fuzzy sets, or directly within the software using fully continuous values, where a cross-over point of 0.5 represents maximum ambiguity (Ragin 2000). We select fuzzy set logic due the variability in conditions being measured and the additional value added by placing importance on differing levels of membership within a set. This becomes particularly useful in the study of social phenomena, as is being studied. Often, due to logic space, sub-elements of a condition are calibrated (e.g., level of local embeddedness) and combined into a larger condition (e.g., training). We note that calibration of the data is an iterative process that combines in-depth knowledge of each case to determine elements that constitute what components are "in" or "out" of a set. Once conditions and outcomes are initially calibrated, a truth table is assembled for each community across phases.

We will then use fsQCA software (Ragin 2006) to analyze the truth table. To reduce the number of conditions, we will use theoretical and substantive knowledge from the cases and examine the consistency and coverage of pathway sets. The minimization of the truth table, through Boolean algebra and fuzzy logic, will result in logical equations that describe the combinations of conditions that support a given outcome, or, conversely, the lack of attainment of an outcome (Jordan et al. 2011).

Each outcome – sustainability and resilience – will be analyzed for each condition (coordination, participation, and training) throughout reconstruction phases. In addition, the pathways across coordination, participation and training over time will be analyzed in combination. Finally, each condition and combination of conditions will be analyzed for combined sustainability and resilience. We will assess the usefulness of the pathways using two metrics: *consistency* and *coverage*. Consistency measures the degree to which cases with a given set of factors or conditions exhibit the outcome, where a consistency score of 0.8 is required and coverage measures the degree to which a given pathway explains the cases analyzed, indicating the relevancy of each pathway (Rihoux and Ragin 2009). During this analysis, we also determine which individual conditions are *necessary* or *sufficient* to produce the outcome, where necessity is a measure of the degree to which the outcome is a subset of the causal condition and sufficiency provides a measure of the degree to which the causal condition is a subset of the outcome. We will conduct this analysis for sustainability and resiliency independently, and then combined.

CONCLUSIONS AND RELEVANCE

We have outlined future methodology to understand and analyze the combination of three key process factors that are posited to affect sustainability and resilience of infrastructure. This research challenges conventional wisdom; it focuses on the development of the adaptive *processes* that are necessary for resilient systems. As a result, it builds a theory of reconstruction process pathways, including coordination, participation, and training that enable resilient and sustainable infrastructure. There is a dearth of information regarding the processes used in these settings for different project phases and how these processes combine to influence sustainable and resilient infrastructure. To address these gaps we will apply fsQCA in a novel manner to analyze rebuilding through snapshots of multiple project phases. Future findings will not only contribute to our intellectual understanding of post-disaster processes and theory, but also facilitate recommendations for communities preparing for, or planning after, a future disaster event.

The proposed research will contribute to theory of coordination across agencies and organizations that are under time pressures without long histories of collaboration and coordination. It will document the network structure to coordinate work and distribute information for post-disaster reconstruction in rapid, pressured environments and document the network evolution over time. By unpacking participation types, including decision-making, implementation, benefit, and evaluation, we will be able to document participation and determine its influence on resilient and sustainable infrastructure. There is little work to date in the literature on stakeholder training strategies, particularly in post-disaster settings, that transfer knowledge to community members. By studying the directional flow of training, the degree of tacitness of knowledge transfer, and the degree of visualization used, we will be able to make contributions regarding the types of training used in the design, construction, and operations and maintenance phases that enable knowledge transfer.

Finally, this research uniquely selects, and operationalizes, sustainability and resilience as system outcomes. While sustainability has developed substantial measurement indicators, resilience is still in its relative infancy. Building on literature definitions we propose a new method of using network analytics to understand and measure resilience using robustness, redundancy, resourcefulness, and rapidity as foundational pillars that align with network properties.

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