Working Paper Proceedings

15th Engineering Project Organization Conference
with
5th International Megaprojects Workshop
Stanford Sierra Camp, California
June 5-7, 2017

Framework for Assessing Resilience in the Communication Networks of AEC Teams

Katherine Maslak, University of Florida, USA

Bryan Franz, University of Florida, USA

Robert Leicht, The Pennsylvania State University, USA

Proceedings Editors
Ashwin Mahalingam, IIT Madras, Tripp Shealy, Virginia Tech, and Nuno Gil, University of Manchester

FRAMEWORK FOR ASSESSING RESILIENCE IN THE COMMUNICATION NETWORKS OF AEC TEAMS

Katherine Maslak[1], Bryan Franz, Ph.D.[2] and Robert Leicht, Ph.D.[3]

ABSTRACT

Architecture, engineering and construction (AEC) teams experience frequent changes in membership while seeing a project through to completion. While some of these changes are planned (e.g. phased involvement, role reassignment), others are unexpected (e.g. career change, sudden downsizing). Too many poorly planned or unexpected changes in membership can bring communication to a standstill and impair a team's ability to deliver a successful project. By examining literature from civil engineering, as well as recent studies on network and team science, we propose a conceptual framework that places the formation, disruption and recovery cycle of communication networks in the context of a construction project. The purpose of this framework is to gain a better understanding of resilient communication networks at the project-level. These types of networks have a structure and composition that enables teams to retain a high degree connectivity despite frequent changes in team membership and to quickly recover any lost lines of communication needed to deliver a successful project. The study of disruptive events and their impact on social systems can readily crossover from AEC teams into other research domains, making contributions to literature in both organizational science and social network analysis.

KEYWORDS

Social network analysis, SNA, project performance, robustness, rapidity

INTRODUCTION

Information flow is critical to successful project delivery. Multidisciplinary teams of architects, engineers and contractors on construction projects have been described as "information processing" systems (Jin and Levitt 1996). Under this view, individual team members process information by sending and receiving messages along specific lines of communication. The pattern of contact created by the flow of those messages over time forms a communication network (Monge and Contractor 2013). The changes in team composition and structure (e.g. phased involvement, role reassignment) that occur with some regularity on construction projects can often disrupt these networks. Network disruptions limit information flow and impair the team's ability to plan and deliver a successful project. The question for AEC project teams, then, is *how to form and maintain effective communication networks that are resilient to these types of disruption?* This research presents a conceptual framework for answering that question. The framework organizes literature on communication

[1] PhD Student, University of Florida, Gainesville, FL: kmaslak@ufl.edu

[2] Assistant Professor, University of Florida, Gainesville, FL: bfranz@ufl.edu

[3] Associate Professor, Penn State University, University Park, PA: rmleicht@engr.psu.edu

networks, team composition, and resilience into a roadmap for further study. Resilience in this context is taken to mean the ability of a communication network to resist or minimize the negative consequences of disruptions, and to recover quickly from those disruptions (Bruneau et al. 2003).

BACKGROUND

For the past two decades, the construction industry has been under pressure to improve its project delivery process in order to meet increasing client demands for higher quality products and services with lower times to market. Specifically, the industry has been criticized for its extreme fragmentation of trades and engineering disciplines, adversarial culture and reluctance to embrace new technologies (Latham 1994, Egan 1998). Thus, there are ongoing efforts that include improving process integration that reduces rework and design errors (Dainty et al. 2001), developing high performance teams that operate more collaboratively (Mollaoglu-Korkmaz et al. 2011, Di Marco and Taylor 2011) and to exploring long-term alliances through public-private partnerships (PPP) or integrated project delivery (IPD) (Lahdenperä 2012, El Asmar et al. 2013). Effective communication is at the heart of each of these efforts and empirical research suggests that project success is influenced by the strength of communication channels (Bowen and Edwards 1996, Phua and Rowlinson 2004).

Communication networks are particularly relevant in the context of AEC project teams because of the presence of both formalized and emergent patterns of information exchange. Contract arrangements signed at the very beginning of the project mandate a certain formality, frequency and structure for communication among team members. The construction industry has refined a set of communication processes and protocols (e.g. organizational charts, standard weekly owner-architect-contractor meetings) that support these arrangements. However, as the project advances, a new pattern of communication often emerges by necessity to ensure that the right type of information is being exchanged at the right time with the right person (Javernick-Will et al. 2010). Similarly, Macomber and Howell (2003) characterize construction and engineering projects as a “network of commitments,” rather than a network of tasks or activities. These overlapping layers of structure for how teams communicate have not been widely explored, despite the substantial potential for conflict that may undermine the flow of information necessary for project success.

DEFINING RESILIENCE IN CONTEXT

Resilience is the ability of a system to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize disruption and mitigate the effects of future disasters (Bruneau et al. 2003). In the wakes of Hurricanes Katrina in 2005 and Sandy in 2012, the resilience of infrastructure systems, including bridges, dams and power distribution grids, became a prominent topic of research. Resilience is now commonly included as a design objective and major requirement in civil and engineering projects performed by the U.S. Army Corps of Engineers and the General Services Administration. However, outside of infrastructure applications, resilience can be a confusing term. There has been widespread debate about how resilience is measured, much of which stems from differences in how it is conceptualized. In economics, ecology, psychology and organizational science literature, there is little agreement as to whether resilience is a property of the system (Gunderson 2000), a process (Masten 2001) or the capacity of an individual (Youssef and Luthans 2007). Each of these fields of study conceptualizes resilience within their own context, making it challenging to compare resilience across domains.

This lack of convergence is at least partly attributable to the dynamic nature of the systems being studied (Walker et al. 2004, Manyena 2006). Unlike dams or power distribution grids, the capacity of social systems is consistently changing, making it difficult to design resilience into that system. In an effort to bridge between theories of resilience found in engineering and those in social sciences, we consider resilience as an emergent property of what the system *does*, rather than a static property the system *has* (Park et al. 2013). This means that the resilience of a communication network cannot be determined by examining individual nodes or ties, but can only be understood in how the network performs in its response to disruption. This suggests that, at a given point in time, a communication network has an emergent resilience to a disruptive event that is a function of the structural properties of the network, such as centralization, cohesion and density, as well as node-level attributes.

RESILIENT COMMUNICATION NETWORKS

To understand how a given system responds to disruptions, four properties of resilience—robustness, rapidity, redundancy and resourcefulness—were first identified by Bruneau et al. (2003) and later mathematically expressed by Cimellaro et al. (2010). Taken together, these properties describe a system's ability to restore functionality and "bounce back" from a disruption. Figure 1 graphically depicts these properties of resilience alongside the pattern of loss and restoration following a disruptive event that is referred to as the "resilience triangle" (Bruneau et al. 2003).

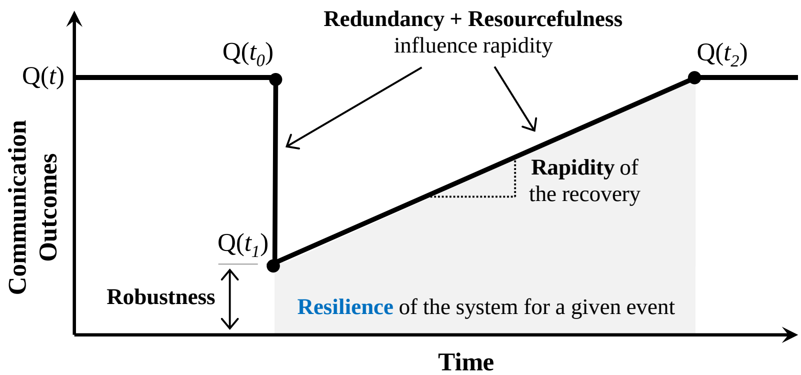

Figure 1. Resilience triangle for a communication network

When applied to communication networks, where their purpose is to enable information exchange, the function Q(t) is a representation of the team's communication over time. After a team is procured, they begin forming network ties, first according to the formal structure offered by the project delivery system, then informally, as necessary to make progress on the project. At some point, the team reaches an optimal level of communication, Q(t_0). Inevitably, a disruptive event, such as the transitioning away of a senior team member occurs and the network loses some of its connectivity. Reduced connectivity leads to drop communication. The impact may be instantaneous, but may also degrade gradually over time until the point of lowest communication, $Q(t_1)$, is reached. The communication that remains, i.e. the difference in communication between $Q(t_0)$ and $Q(t_1)$, is the ***robustness*** of the network to that particular disruptive event. ***Rapidity*** is the average rate of recovery occurring between t_1 and t_2 to recover communication to either pre-disruption levels, such that $Q(t_2) = Q(t_0)$, or another, new optimal level. Both the structural ***redundancy*** in the network and the ***resourcefulness*** of individual team members can influence how the system responds under stress, and are thus more likely to function as antecedents of robustness and rapidity. For example, the presence of structurally equivalent relationships among multiple team members adds redundancy to the network that may enable the team to recover faster from a loss. Similarly, individuals and organizations vary in their response to crisis, and some are more resourceful than others in forming new communication ties to restore connectivity. ***Resilience*** itself is typically quantified as the integral of $Q(t)$ taken between the time of disruption, t_1, and time of full recovery, t_2. Therefore, a resilient communication network for AEC teams is one that retains usefulness in the face of disruptions and one that quickly restores lost communication pathways.

COMPOSITIONAL CHANGE ON CONSTRUCTION PROJECTS

Several researchers question the traditional, static view of projects, suggesting instead that random events and political gamesmanship between individuals make project teams very dynamic (Thietart and Forgues, 1995). Every construction project moves through a predictable set of phases that are characterized by distinct dealings or transactions between team members. Henisz et al. (2012) describe the "displaced agency" of the accumulated costs of independent transactions that occur among the project participants and several terms have arisen to describe the nature of AEC teams: temporary organizations (Berggren et al., 2001); temporary multi-organizations (Cherns and Bryant, 1983), and project-based firms (Whitley, 2006). The common idea spanning each of these terms is the transient and fluid nature of teams in the construction industry.

However, most empirical studies operate under the assumption that project management teams are static—that once selected, individuals are bound together contractually to remain in their pre-assigned, formal roles for the duration of the project. In reality, there are both planned and unplanned changes in the composition of project teams that are viewed as having a negative impact on project performance (Chua et al. 1999, Parker and Skitmore 2004). Planned changes, such as retirements, promotions and the transitions that occur during project phase changes (e.g. from design to construction) typically have less severe consequences. Since project teams have advance notice of these events, they have the opportunity to implement succession planning (Raiden et al. 2004) to capture knowledge from the departing team member and to train their successor. Unplanned changes may include individuals leaving to pursue a better career opportunity, individuals suffering jobsite injuries aor firms going out business mid-project. These changes are viewed as turnover and give the project team little time to prepare and respond. In network science, the coming and going of individuals is often referred to as "churn." There is evidence that churn in the composition of project teams has a negative influence on performance (Wolf et al. 2009, Sasovova et al. 2010), in part due to the structural holes created in the network that take time to repair (Cummings and Cross 2003, Balkundi et al. 2007). Certain network structures are advantageous for minimizing the negative effects of churn or other changes in composition (Zaheer et al. 2005).

In studies of physical communication networks, such as the World Wide Web, authors find they are very robust to random node removal (Albert et al. 2000, Broder et al. 2000). In other words, these networks maintain a consistent level of service despite the removal of persons, or nodes in the network, at random. However, when nodes with the highest degrees (i.e. the most connected) are removed, the networks rapidly degrade (Newman et al. 2002). Another important aspect of network response is time dependency. That is to say, network structure in the present is dependent on the arrangement of nodes and ties in the past. Team composition refers to the surface- and deep-level demographics of all members in the AEC team. Surface-level demographics are readily observable or inferable traits such as age, gender, education, tenure and functional roles of individuals (Horwitz and Horwitz 2007). Deep-level demographics are less obvious and may only become apparent after repeated interactions, such as an individual's knowledge, skills and abilities (Devine and Phillips 2001, Stewart 2006).

TEAM COMPOSITION AND NETWORK STRUCTURE

A fundamental issue in network science is how the characteristics of an individual affect their position in the network. One of the main determinants of emergent network structures is the theory of homophily. Perhaps best expressed with the phrase "birds of feather," homophily states that individuals will form network ties with others who are similar. These similarities may include age, gender, education or any number of other demographic attributes (McPherson and Smith-Lovin 1987). Authors hypothesize that homophily reduces physiological discomfort (Heider 1958) and potential areas of relationship conflict brought about by physical differences (Sherif 1958). Taken to the extreme, Lau and Murnighan (1998) argue that demographic diversity plays a significant role in how teams organize. They cite the presence of "faultlines" that tend to form along one or more surface-level demographic attributes (e.g. age, education) and fragment a team into multiple subgroups. Currently, the construction industry is in a state of transition. The workforce is becoming more diverse, with greater participation from young people, women and minorities (Briscoe 2005, Menches and Abraham 2007), making homophily a particularly relevant theory for explaining how project managers and engineers choose with whom to communicate.

Another theory on network emergence comes from the perspective of social exchange and resource dependency. Beginning with Benson (1975), who defined inter-organizational networks as a political economy, where resources determined a firm's position in the network, exchange theory has successfully been applied to the study of health care delivery (Provan and Milward 1995), corporate leadership (Mizruchi 1996) and alliancing (Larson 1992). The theory itself provides two conditions that are necessary for a communication relation, as a network tie, to emerge: (1) there is a discrepancy in resource needs between two individuals, i.e. one person has information that another needs, and (2) both individuals involved in the resource exchange recognize the value of the relationship. Therefore, a network tie is more likely to form between nodes when there is a sufficient potential for exchange. Additionally, there is an implication that people view relations that minimize their dependence on others and improve their own power or position in the network as having high value (Settoon et al. 1996). Under the information processing view of construction projects, information is a resource being shared and exchanged across disciplines. Thus, exchange theories have value in explaining how communication ties develop among team members on construction projects.

ROLE OF PROJECT DELIVERY SYSTEMS

As construction operations become more complex, they will continue to shift away from the idea of a “general” contractor and, instead, engage a series of specialties that create a ‘quasi-firm’ as described by (Eccles, 1981). Project delivery systems are, in effect, a quasi-firm arrangement in that they provide formality and consistency in the project organization. By necessity, most practitioners are familiar with the standard contract language, procurement procedures and typical lines of communication common in various delivery systems. However, not all project delivery systems are equally structured to allow for the fast information exchanges and effective communications demanded by an increasing fragmented industry. This is evidenced in the multiple empirical studies on project delivery systems that cite communication as an antecedent to project success. Beginning with Konchar and Sanvido’s (1998) seminal study, strong team communication found on Design-Build projects was identified as a predictor of both construction and delivery speed. While not specific to a single delivery system, Sambasivan and Soon (2007) similarly noted that a lack of communication between team members was a primary contributor to project delays. Asmar et al. (2013) found significantly lower RFI processing times and fewer resubmittals on Integrated Project Delivery (IPD) and “IPD-ish” projects, when compared to Design-Bid-Build (DBB) and Construction Manager at Risk (CMR). Most recently, Franz et al. (2017) demonstrate that timely communication is reflective of the cohesiveness of the team and is a significant contributor to cost and quality outcomes. Communication was improved when the primary contractor and select specialty trades were involved early in the design process. Therefore, the project delivery system provides important context for how AEC teams exchange in information exchange and develop their communication networks.

CONCEPTUAL FRAMEWORK

Aggregating each of these concepts together and adding a dimension of time, we propose the research framework shown in Figure 2. This is a dynamic framework, the purpose of which is to understand the impact of resilient communication on project performance. Within the framework, we identify three antecedents that influence the structure of communication networks over time: (1) the contractual arrangements of the project delivery system that formalize roles and expectations for organizations and individuals, (2) the composition of the AEC team, including their available collective knowledge, skills and abilities, as well as the demographic attributes of individual members such as age, gender, education, and tenure in the industry, and (3) the severity and timing a disruptive compositional or role change event. These antecedents influence the structure of the network over three distinct time periods—pre-disruption, recovery and post-disruption—during which the team produces measurable communication outcomes that may be used to assess the resilience of their network to a given disruptive event. In alignment with recent research (Bruneau et al. 2003, Cimellaro et al. 2010), we conceptualize the assessment of resilience across four dimensions: (a) *rapidity* of network recovery to pre-disruption levels of communication, (b) *robustness* of the network to retain a minimum level of communication following a change event, (c) *redundancy* of roles and structure in the network, and (d) the *resourcefulness* of individuals to assume new roles or form new ties. Lastly, the interaction of these properties are considered as antecedents to long-term project outcomes. Long-term project outcomes are typically measured through the AEC team's ability to mitigate the 'iron triangle' (Atkinson 1999) in which a team must deliver a quality product, on-schedule and within budget. However, as owners continue to place greater emphasis on lifecycle value of their projects, the concept of long-term outcomes can be extended to include sustainability, operations and maintenance, and facility flexibility.

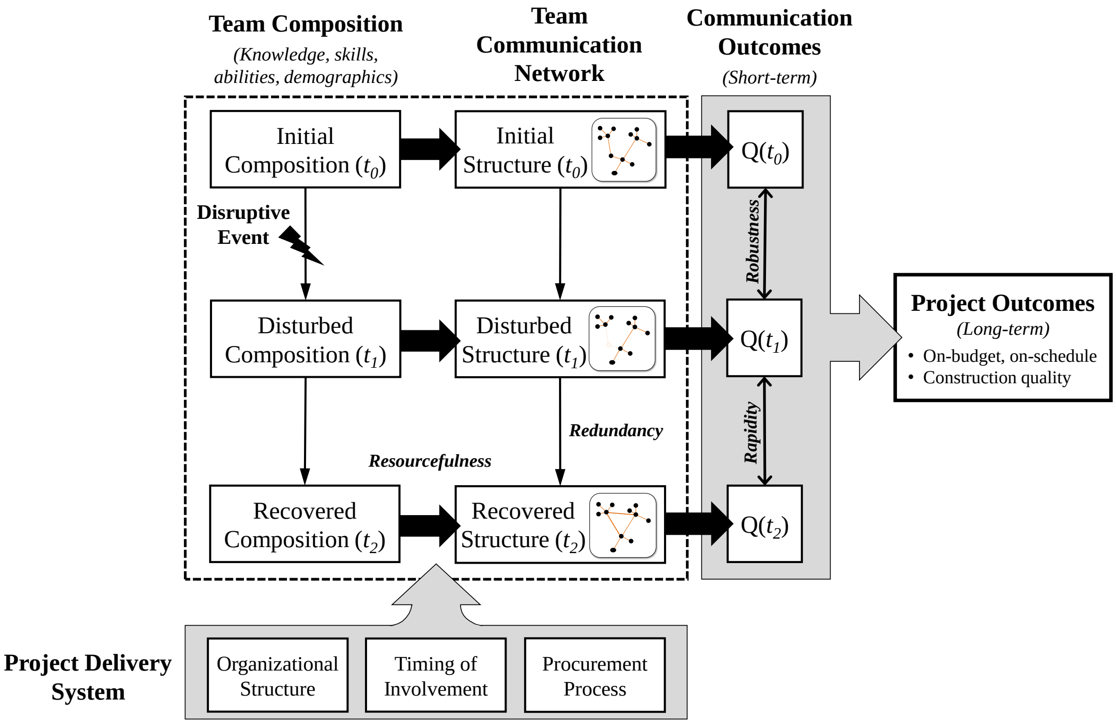

Figure 2. Conceptual framework of resilience in communication networks

Existing research on resilience in communication networks has several limitations, which this framework strives to overcome. First, many network studies in engineering use only cross-sectional methodologies that do not consider the process by which the networks evolve over time. These studies tend to assume that network structures are relatively stable in the long-term, which discounts the considerable, short-term changes in ties and node involvement often found in practice (Kossinets and Watts 2006). However, over the past two decades, there has been an increasing emphasis on longitudinal methods, specifically in the fields of organizational behavior and team science, to understand network evolution. These types of studies reveal new insights about many types of networks, including coordination networks following hazard events (Opdyke et al. 2016). Second, few studies adequately define and operationalize resilience outside of civil, infrastructure and other types of physical systems. The concept of resilience in physical systems is well-established, where performance can be expressed as a percentage of their static design capacity (e.g. kilowatts generated, customers served) at any given time. Resilience to a disruptive event is thus mathematically defined as the normalized integral of the performance function taken between the time of the event and the time of full system recovery (Bruneau et al. 2003). However, for social systems with dynamic capacities, such as the communication networks found in AEC project teams, performance must be expressed and measured differently to derive a meaningful operationalization of resilience. Lastly, prior research does not focus on identifying the underlying mechanisms of action, such as the information processing process, for how resilience in communication networks lead to desirable project outcomes.

Going forward, we intend to test the conceptual framework in assessing resilience by conducting a pilot case study that tracks the structure of an active AEC team's communication network and their associated communication outcomes over the project duration. We believe that email messages between individual team members may be used to construct directed, longitudinal communication networks of the project team. Tie strength in these could then be defined as the number of messages sent from one team member to another within any desired period. In this manner, changes in global-level properties of the communication network on a project, such as density and centralization, can be examined for a relationship with compositional and role change events occurring within the AEC team. These network properties could also be examined alongside communication outcomes, which could include percent plan complete (PPC) from the use of the Last Planner System or response latency. Both outcomes are indicative of the effectiveness of the team's communication network, which is necessary to quantitatively assess the rapidity and robustness dimensions of resilience for a given disruption. More qualitative methods, such as network ethnography would be necessary to understand the redundancy of the network, as well as the resourcefulness displayed by the AEC team during the recovery period.

CONCLUSIONS

By presenting a conceptual framework, this paper provides new insights into how resilience of communication networks may be studied and applied in AEC teams. A better understanding of the process influencing resilience in communication networks can improve the work flow, coordination and efficiency of information exchanges on complex, construction and engineering projects. By linking patterns in team composition, communication network structure and resilience with project outcomes (e.g. budget and schedule), there are implications for predicting performance based on the how the network evolves. The predictive capacity offered by this research can make project teams more agile in responding to both internal and external disruptions. For example, we can better understand the attributes and role structures needed to replace a departing team member to maintain network functionality, or we can consider big data analysis of communication network vulnerabilities, such as the identification of overly connected team members whose departure would severely reduce project performance. Thus, this research has the potential to inform the formation and management of more resilient communication networks in AEC teams.

REFERENCES

Balkundi, P., Kilduff, M., Barsness, Z. I., & Michael, J. H. (2007). Demographic antecedents and performance consequences of structural holes in work teams. *Journal of Organizational Behavior*, *28*(2), 241-260.

Benson, J. K. (1975). The interorganizational network as a political economy. *Administrative science quarterly*, 229-249.

Berggren, C. Soderlund, J. and Anderson, C. (2001). Clients, contractors, and consultants: the consequences of organizational fragmentation in contemporary project environments. *Project Management Journal*, 32(3), 39-48.

Bowen, P. A., and Edwards, P. J. (1996). Interpersonal communication in cost planning during the building design phase. *Construction Management & Economics*, *14*(5), 395-404.

Briscoe, G. (2005). Women and minority groups in UK construction: recent trends. *Construction Management and Economics*, *23*(10), 1001-1005.

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W.A. and von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra*, 19(4), 733-752.

Cherns, A. and Bryant, D. (1983). Studying the client's role in construction management. *Construction Management and Economics*, 2(2), 177-184.

Chua, D. K. H., Kog, Y. C., and Loh, P. K. (1999). Critical success factors for different project objectives. *Journal of construction engineering and management*, *125*(3), 142-150.

Cimellaro, G. P., Reinhorn, A. M., and Bruneau, M. (2010). Framework for analytical quantification of disaster resilience. *Engineering Structures*, *32*(11), 3639-3649.

Cummings, J. N., and Cross, R. (2003). Structural properties of work groups and their consequences for performance. *Social networks*, *25*(3), 197-210.

Dainty, A. R., Millett, S. J., and Briscoe, G. H. (2001). New perspectives on construction supply chain integration. *Supply chain management: An international journal*, 6(4), 163-173.

Devine, D.J., and Philips, J.L. (2001). Do smart teams do better: A meta-analysis of cognitive ability and team performance. *Small Group Research*, 32: 507-532.

Di Marco, M. K., and Taylor, J. E. (2011). The impact of cultural boundary spanners on global project network performance. *The Engineering Project Organization Journal*, *1*(1), 27-39.

Eccles, R.G. (1981). The quasifirms in the construction industry. *Journal of Economic Behavior and Organization* (2), 335-357.

Egan, J. (1998). *Rethinking Construction*, London: DETR/Stationery Office.

El Asmar, M., Hanna, A. S., and Loh, W. Y. (2013). Quantifying performance for the integrated project delivery system as compared to established delivery systems. *Journal of Construction Engineering and Management*, 139(11), 04013012.

Franz, B., Leicht, R., Molenaar, K. and Messner, J. (2017). Impact of team integration and group cohesion on project delivery performance. *Journal of Construction Engineering and Management,* DOI: 10.1061/(ASCE)CO.1943-7862.0001219.

Gunderson, L. H. (2000). Ecological resilience--in theory and application. *Annual review of ecology and systematics*, 425-439.
Heider, F. (1958). *The Psychology of Interpersonal Relations*. New York: Wiley.
Henisz, W.J., Levitt, R.E. and Scott, R. (2012). Toward a unified theory of project governance: Economic, sociological and psychological supports for relational contracting. *The Engineering Project Organizations Journal*, 2(1-2), 37-55.
Horwitz, S. K., and Horwitz, I. B. (2007). The effects of team diversity on team outcomes: A meta-analytic review of team demography. *Journal of management*, *33*(6), 987-1015.
Javernick-Will, A. N., and Scott, W. R. (2010). Who needs to know what? Institutional knowledge and global projects. *Journal of Construction Engineering and Management*, *136*(5), 546-557.
Jin, Y., and Levitt, R. E. (1996). The virtual design team: A computational model of project organizations. *Computational & Mathematical Organization Theory*, 2(3), 171–195.
Konchar, M. and Sanvido, V. (1998). Comparison of US project delivery systems. *Journal of Construction Engineering and Management*, 124(6), 435-444.
Kossinets, G., and Watts, D. J. (2006). Empirical analysis of an evolving social network. S*cience*, *311*(5757), 88-90.
Lahdenperä, P. (2012). Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. *Construction Management and Economics*, 30(1), 57-79.
Larson, A. (1992). Network dyads in entrepreneurial settings: a study of the governance of exchange relationships. *Administrative Science Quarterly*, Vol. 37, pp.76-104.
Latham, S. M. (1994). *Constructing the Team*. London: HM Stationery Office.
Lau, D. C., and Murnighan, J. K. (1998). Demographic diversity and faultlines: The compositional dynamics of organizational groups. *Academy of Management Review*, *23*(2), 325-340.
Macomber, H., and Howell, G. (2003). Linguistic action: Contributing to the theory of lean construction. In *Proceedings of the 11th Annual Meeting of the International Group for Lean Construction* (pp. 1-10).
Manyena, S. B. (2006). The concept of resilience revisited. *Disasters*, *30*(4), 434-450.
Masten, A. S. (2001). Ordinary magic: Resilience processes in development. *American Psychologist*, *56*, 227.
McPherson, J. M., and Smith-Lovin, L. (1987). Homophily in voluntary organizations: Status distance and the composition of face-to-face groups. *American Sociological Review*, 370-379.
Menches, C. L., and Abraham, D. M. (2007). Women in construction—tapping the untapped resource to meet future demands. *Journal of Construction Engineering and Management*, *133*(9), 701-707.
Mizruchi, M. S. (1996). What do interlocks do? An analysis, critique, and assessment of research on interlocking directorates. *Annual Review of Sociology*, 271-298.
Mollaoglu-Korkmaz, S., Swarup, L., and Riley, D. (2011). Delivering sustainable, high-performance buildings: Influence of project delivery methods on integration and project outcomes. *Journal of Management in Engineering*, 29(1), 71-78.

Monge, P. R., and Contractor, N. (2003). *Theories of Communication Networks*. New York: Oxford University Press

Newman, M. E., Forrest, S., and Balthrop, J. (2002). Email networks and the spread of computer viruses. *Physical Review E*, *66*(3), 035101.

Opdyke, A., Lepropre, F., Javernick-Will, A., and Koschmann, M. (2016). Inter-organizational resource coordination in post-disaster infrastructure recovery. *Construction Management and Economics*, 1-17.

Park, J., Seager, T. P., Rao, P. S. C., Convertino, M., and Linkov, I. (2013). Integrating risk and resilience approaches to catastrophe management in engineering systems. *Risk Analysis*, 33(3), 356-367.

Parker, S. K., and Skitmore, M. (2005). Project management turnover: causes and effects on project performance. *International Journal of Project Management*, *23*(3), 205-214.

Phua, F. T., and Rowlinson, S. (2004). How important is cooperation to construction project success? A grounded empirical quantification. *Engineering, Construction and Architectural Management*, *11*(1), 45-54.

Provan, K. G., and Milward, H. B. (1995). A preliminary theory of interorganizational network effectiveness: A comparative study of four community mental health systems. *Administrative science quarterly*, 1-33.

Raiden, A. B., Dainty, A. R., and Neale, R. H. (2004). Current barriers and possible solutions to effective project team formation and deployment within a large construction organization. *International Journal of Project Management*, 22(4), 309-316.

Sambasivan, M. and Soon, Y. W. (2007). Causes and effects of delays in Malaysian construction industry. *International Journal of project management*, 25(5), 517-526.

Sasovova, Z., Mehra, A., Borgatti, S. P., and Schippers, M. C. (2010). Network churn: The effects of self-monitoring personality on brokerage dynamics. *Administrative Science Quarterly*, *55*(4), 639-670.

Settoon, R. P., Bennett, N., and Liden, R. C. (1996). Social exchange in organizations: Perceived organizational support, leader–member exchange, and employee reciprocity. *Journal of Applied Psychology*, 81(3), 219.

Sherif, M. (1958). Superordinate goals in the reduction of inter-group conflicts. *American Journal of Sociology*, 63, 349-356.

Stewart, G. (2006). A meta-analytic review of relationships between team design features and team performance. *Journal of Management*, 32: 29-54.

Thietart, R. and Forgues, B. (1995). Chaos theory and organizations. *Organization Science*, 6(1), 19-31.

Walker, B., Holling, C. S., Carpenter, S. R., and Kinzig, A. (2004). Resilience, adaptability and transformability in social--ecological systems. *Ecology and society*, *9*(2), 5.

Whitley, R. (2006). Project-based firms: new organizational form or variations on a theme? *Industrial and Corporate Change*, 15(1), 77-99.

Wolf, T., Schroter, A., Damian, D., and Nguyen, T. (2009, May). Predicting build failures using social network analysis on developer communication. In *Proceedings of the 31st International Conference on Software Engineering* (pp. 1-11). IEEE Computer Society.

Youssef, C. M., and Luthans, F. (2007). Positive organizational behavior in the workplace the impact of hope, optimism, and resilience. *Journal of Management*, *33*, 774-800.

Zaheer, A., & Bell, G. G. (2005). Benefiting from network position: firm capabilities, structural holes, and performance. *Strategic Management Journal*, *26*(9), 809-825.

FRAMEWORK FOR ASSESSING RESILIENCE IN THE COMMUNICATION NETWORKS OF AEC TEAMS

Katherine Maslak[1], Bryan Franz, Ph.D.[2] and Robert Leicht, Ph.D.[3]

ABSTRACT

Architecture, engineering and construction (AEC) teams experience frequent changes in membership while seeing a project through to completion. While some of these changes are planned (e.g. phased involvement, role reassignment), others are unexpected (e.g. career change, sudden downsizing). Too many poorly planned or unexpected changes in membership can bring communication to a standstill and impair a team's ability to deliver a successful project. By examining literature from civil engineering, as well as recent studies on network and team science, we propose a conceptual framework that places the formation, disruption and recovery cycle of communication networks in the context of a construction project. The purpose of this framework is to gain a better understanding of resilient communication networks at the project-level. These types of networks have a structure and composition that enables teams to retain a high degree connectivity despite frequent changes in team membership and to quickly recover any lost lines of communication needed to deliver a successful project. The study of disruptive events and their impact on social systems can readily crossover from AEC teams into other research domains, making contributions to literature in both organizational science and social network analysis.

KEYWORDS

Social network analysis, SNA, project performance, robustness, rapidity

INTRODUCTION

Information flow is critical to successful project delivery. Multidisciplinary teams of architects, engineers and contractors on construction projects have been described as "information processing" systems (Jin and Levitt 1996). Under this view, individual team members process information by sending and receiving messages along specific lines of communication. The pattern of contact created by the flow of those messages over time forms a communication network (Monge and Contractor 2013). The changes in team composition and structure (e.g. phased involvement, role reassignment) that occur with some regularity on construction projects can often disrupt these networks. Network disruptions limit information flow and impair the team's ability to plan and deliver a successful project. The question for AEC project teams, then, is *how to form and maintain effective communication networks that are resilient to these types of disruption?* This research presents a conceptual framework for answering that question. The framework organizes literature on communication

[1] PhD Student, University of Florida, Gainesville, FL: kmaslak@ufl.edu
[2] Assistant Professor, University of Florida, Gainesville, FL: bfranz@ufl.edu
[3] Associate Professor, Penn State University, University Park, PA: rmleicht@engr.psu.edu

networks, team composition, and resilience into a roadmap for further study. Resilience in this context is taken to mean the ability of a communication network to resist or minimize the negative consequences of disruptions, and to recover quickly from those disruptions (Bruneau et al. 2003).

BACKGROUND

For the past two decades, the construction industry has been under pressure to improve its project delivery process in order to meet increasing client demands for higher quality products and services with lower times to market. Specifically, the industry has been criticized for its extreme fragmentation of trades and engineering disciplines, adversarial culture and reluctance to embrace new technologies (Latham 1994, Egan 1998). Thus, there are ongoing efforts that include improving process integration that reduces rework and design errors (Dainty et al. 2001), developing high performance teams that operate more collaboratively (Mollaoglu-Korkmaz et al. 2011, Di Marco and Taylor 2011) and to exploring long-term alliances through public-private partnerships (PPP) or integrated project delivery (IPD) (Lahdenperä 2012, El Asmar et al. 2013). Effective communication is at the heart of each of these efforts and empirical research suggests that project success is influenced by the strength of communication channels (Bowen and Edwards 1996, Phua and Rowlinson 2004).

Communication networks are particularly relevant in the context of AEC project teams because of the presence of both formalized and emergent patterns of information exchange. Contract arrangements signed at the very beginning of the project mandate a certain formality, frequency and structure for communication among team members. The construction industry has refined a set of communication processes and protocols (e.g. organizational charts, standard weekly owner-architect-contractor meetings) that support these arrangements. However, as the project advances, a new pattern of communication often emerges by necessity to ensure that the right type of information is being exchanged at the right time with the right person (Javernick-Will et al. 2010). Similarly, Macomber and Howell (2003) characterize construction and engineering projects as a "network of commitments," rather than a network of tasks or activities. These overlapping layers of structure for how teams communicate have not been widely explored, despite the substantial potential for conflict that may undermine the flow of information necessary for project success.

DEFINING RESILIENCE IN CONTEXT

Resilience is the ability of a system to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize disruption and mitigate the effects of future disasters (Bruneau et al. 2003). In the wakes of Hurricanes Katrina in 2005 and Sandy in 2012, the resilience of infrastructure systems, including bridges, dams and power distribution grids, became a prominent topic of research. Resilience is now commonly included as a design objective and major requirement in civil and engineering projects performed by the U.S. Army Corps of Engineers and the General Services Administration. However, outside of infrastructure applications, resilience can be a confusing term. There has been widespread debate about how resilience is measured, much of which stems from differences in how it is conceptualized. In economics, ecology, psychology and organizational science literature, there is little agreement as to whether resilience is a property of the system (Gunderson 2000), a process (Masten 2001) or the capacity of an individual (Youssef and Luthans 2007). Each of these fields of study conceptualizes resilience within their own context, making it challenging to compare resilience across domains.

This lack of convergence is at least partly attributable to the dynamic nature of the systems being studied (Walker et al. 2004, Manyena 2006). Unlike dams or power distribution grids, the capacity of social systems is consistently changing, making it difficult to design resilience into that system. In an effort to bridge between theories of resilience found in engineering and those in social sciences, we consider resilience as an emergent property of what the system *does*, rather than a static property the system *has* (Park et al. 2013). This means that the resilience of a communication network cannot be determined by examining individual nodes or ties, but can only be understood in how the network performs in its response to disruption. This suggests that, at a given point in time, a communication network has an emergent resilience to a disruptive event that is a function of the structural properties of the network, such as centralization, cohesion and density, as well as node-level attributes.

RESILIENT COMMUNICATION NETWORKS

To understand how a given system responds to disruptions, four properties of resilience—robustness, rapidity, redundancy and resourcefulness—were first identified by Bruneau et al. (2003) and later mathematically expressed by Cimellaro et al. (2010). Taken together, these properties describe a system's ability to restore functionality and "bounce back" from a disruption. Figure 1 graphically depicts these properties of resilience alongside the pattern of loss and restoration following a disruptive event that is referred to as the "resilience triangle" (Bruneau et al. 2003).

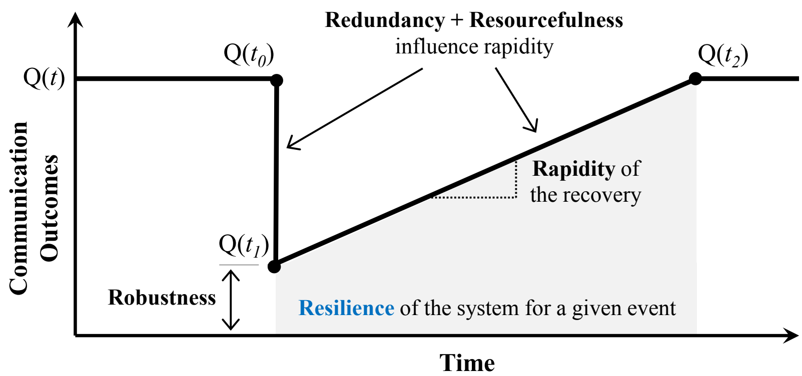

Figure 1. Resilience triangle for a communication network

When applied to communication networks, where their purpose is to enable information exchange, the function Q(t) is a representation of the team's communication over time. After a team is procured, they begin forming network ties, first according to the formal structure offered by the project delivery system, then informally, as necessary to make progress on the project. At some point, the team reaches an optimal level of communication, Q(t_0). Inevitably, a disruptive event, such as the transitioning away of a senior team member occurs and the network loses some of its connectivity. Reduced connectivity leads to drop communication. The impact may be instantaneous, but may also degrade gradually over time until the point of lowest communication, Q(t_1), is reached. The communication that remains, i.e. the difference in communication between Q(t_0) and Q(t_1), is the ***robustness*** of the network to that particular disruptive event. ***Rapidity*** is the average rate of recovery occurring between t_1 and t_2 to recover communication to either pre-disruption levels, such that Q(t_2) = Q(t_0), or another, new optimal level. Both the structural ***redundancy*** in the network and the ***resourcefulness*** of individual team members can influence how the system responds under stress, and are thus more likely to function as antecedents of robustness and rapidity. For example, the presence of structurally equivalent relationships among multiple team members adds redundancy to the network that may enable the team to recover faster from a loss. Similarly, individuals and organizations vary in their response to crisis, and some are more resourceful than others in forming new communication ties to restore connectivity. ***Resilience*** itself is typically quantified as the integral of Q(t) taken between the time of disruption, t_1, and time of full recovery, t_2. Therefore, a resilient communication network for AEC teams is one that retains usefulness in the face of disruptions and one that quickly restores lost communication pathways.

COMPOSITIONAL CHANGE ON CONSTRUCTION PROJECTS

Several researchers question the traditional, static view of projects, suggesting instead that random events and political gamesmanship between individuals make project teams very dynamic (Thietart and Forgues, 1995). Every construction project moves through a predictable set of phases that are characterized by distinct dealings or transactions between team members. Henisz et al. (2012) describe the "displaced agency" of the accumulated costs of independent transactions that occur among the project participants and several terms have arisen to describe the nature of AEC teams: temporary organizations (Berggren et al., 2001); temporary multi-organizations (Cherns and Bryant, 1983), and project-based firms (Whitley, 2006). The common idea spanning each of these terms is the transient and fluid nature of teams in the construction industry.

However, most empirical studies operate under the assumption that project management teams are static—that once selected, individuals are bound together contractually to remain in their pre-assigned, formal roles for the duration of the project. In reality, there are both planned and unplanned changes in the composition of project teams that are viewed as having a negative impact on project performance (Chua et al. 1999, Parker and Skitmore 2004). Planned changes, such as retirements, promotions and the transitions that occur during project phase changes (e.g. from design to construction) typically have less severe consequences. Since project teams have advance notice of these events, they have the opportunity to implement succession planning (Raiden et al. 2004) to capture knowledge from the departing team member and to train their successor. Unplanned changes may include individuals leaving to pursue a better career opportunity, individuals suffering jobsite injuries aor firms going out business mid-project. These changes are viewed as turnover and give the project team little time to prepare and respond. In network science, the coming and going of individuals is often referred to as "churn." There is evidence that churn in the composition of project teams has a negative influence on performance (Wolf et al. 2009, Sasovova et al. 2010), in part due to the structural holes created in the network that take time to repair (Cummings and Cross 2003, Balkundi et al. 2007). Certain network structures are advantageous for minimizing the negative effects of churn or other changes in composition (Zaheer et al. 2005).

In studies of physical communication networks, such as the World Wide Web, authors find they are very robust to random node removal (Albert et al. 2000, Broder et al. 2000). In other words, these networks maintain a consistent level of service despite the removal of persons, or nodes in the network, at random. However, when nodes with the highest degrees (i.e. the most connected) are removed, the networks rapidly degrade (Newman et al. 2002). Another important aspect of network response is time dependency. That is to say, network structure in the present is dependent on the arrangement of nodes and ties in the past. Team composition refers to the surface- and deep-level demographics of all members in the AEC team. Surface-level demographics are readily observable or inferable traits such as age, gender, education, tenure and functional roles of individuals (Horwitz and Horwitz 2007). Deep-level demographics are less obvious and may only become apparent after repeated interactions, such as an individual's knowledge, skills and abilities (Devine and Phillips 2001, Stewart 2006).

TEAM COMPOSITION AND NETWORK STRUCTURE

A fundamental issue in network science is how the characteristics of an individual affect their position in the network. One of the main determinants of emergent network structures is the theory of homophily. Perhaps best expressed with the phrase "birds of feather," homophily states that individuals will form network ties with others who are similar. These similarities may include age, gender, education or any number of other demographic attributes (McPherson and Smith-Lovin 1987). Authors hypothesize that homophily reduces physiological discomfort (Heider 1958) and potential areas of relationship conflict brought about by physical differences (Sherif 1958). Taken to the extreme, Lau and Murnighan (1998) argue that demographic diversity plays a significant role in how teams organize. They cite the presence of "faultlines" that tend to form along one or more surface-level demographic attributes (e.g. age, education) and fragment a team into multiple subgroups. Currently, the construction industry is in a state of transition. The workforce is becoming more diverse, with greater participation from young people, women and minorities (Briscoe 2005, Menches and Abraham 2007), making homophily a particularly relevant theory for explaining how project managers and engineers choose with whom to communicate.

Another theory on network emergence comes from the perspective of social exchange and resource dependency. Beginning with Benson (1975), who defined inter-organizational networks as a political economy, where resources determined a firm's position in the network, exchange theory has successfully been applied to the study of health care delivery (Provan and Milward 1995), corporate leadership (Mizruchi 1996) and alliancing (Larson 1992). The theory itself provides two conditions that are necessary for a communication relation, as a network tie, to emerge: (1) there is a discrepancy in resource needs between two individuals, i.e. one person has information that another needs, and (2) both individuals involved in the resource exchange recognize the value of the relationship. Therefore, a network tie is more likely to form between nodes when there is a sufficient potential for exchange. Additionally, there is an implication that people view relations that minimize their dependence on others and improve their own power or position in the network as having high value (Settoon et al. 1996). Under the information processing view of construction projects, information is a resource being shared and exchanged across disciplines. Thus, exchange theories have value in explaining how communication ties develop among team members on construction projects.

ROLE OF PROJECT DELIVERY SYSTEMS

As construction operations become more complex, they will continue to shift away from the idea of a "general" contractor and, instead, engage a series of specialties that create a 'quasi-firm' as described by (Eccles, 1981). Project delivery systems are, in effect, a quasi-firm arrangement in that they provide formality and consistency in the project organization. By necessity, most practitioners are familiar with the standard contract language, procurement procedures and typical lines of communication common in various delivery systems. However, not all project delivery systems are equally structured to allow for the fast information exchanges and effective communications demanded by an increasing fragmented industry. This is evidenced in the multiple empirical studies on project delivery systems that cite communication as an antecedent to project success. Beginning with Konchar and Sanvido's (1998) seminal study, strong team communication found on Design-Build projects was identified as a predictor of both construction and delivery speed. While not specific to a single delivery system, Sambasivan and Soon (2007) similarly noted that a lack of communication between team members was a primary contributor to project delays. Asmar et al. (2013) found significantly lower RFI processing times and fewer resubmittals on Integrated Project Delivery (IPD) and "IPD-ish" projects, when compared to Design-Bid-Build (DBB) and Construction Manager at Risk (CMR). Most recently, Franz et al. (2017) demonstrate that timely communication is reflective of the cohesiveness of the team and is a significant contributor to cost and quality outcomes. Communication was improved when the primary contractor and select specialty trades were involved early in the design process. Therefore, the project delivery system provides important context for how AEC teams exchange in information exchange and develop their communication networks.

CONCEPTUAL FRAMEWORK

Aggregating each of these concepts together and adding a dimension of time, we propose the research framework shown in Figure 2. This is a dynamic framework, the purpose of which is to understand the impact of resilient communication on project performance. Within the framework, we identify three antecedents that influence the structure of communication networks over time: (1) the contractual arrangements of the project delivery system that formalize roles and expectations for organizations and individuals, (2) the composition of the AEC team, including their available collective knowledge, skills and abilities, as well as the demographic attributes of individual members such as age, gender, education, and tenure in the industry, and (3) the severity and timing a disruptive compositional or role change event. These antecedents influence the structure of the network over three distinct time periods—pre-disruption, recovery and post-disruption—during which the team produces measurable communication outcomes that may be used to assess the resilience of their network to a given disruptive event. In alignment with recent research (Bruneau et al. 2003, Cimellaro et al. 2010), we conceptualize the assessment of resilience across four dimensions: (a) *rapidity* of network recovery to pre-disruption levels of communication, (b) *robustness* of the network to retain a minimum level of communication following a change event, (c) *redundancy* of roles and structure in the network, and (d) the *resourcefulness* of individuals to assume new roles or form new ties. Lastly, the interaction of these properties are considered as antecedents to long-term project outcomes. Long-term project outcomes are typically measured through the AEC team's ability to mitigate the 'iron triangle' (Atkinson 1999) in which a team must deliver a quality product, on-schedule and within budget. However, as owners continue to place greater emphasis on lifecycle value of their projects, the concept of long-term outcomes can be extended to include sustainability, operations and maintenance, and facility flexibility.

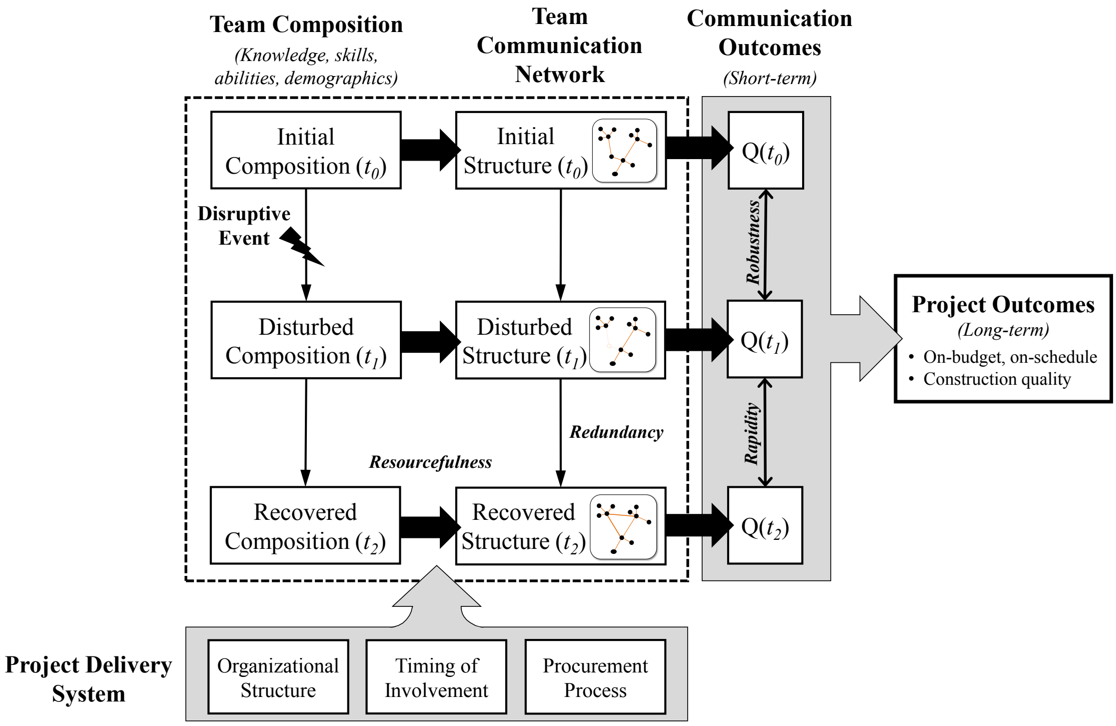

Figure 2. Conceptual framework of resilience in communication networks

Existing research on resilience in communication networks has several limitations, which this framework strives to overcome. First, many network studies in engineering use only cross-sectional methodologies that do not consider the process by which the networks evolve over time. These studies tend to assume that network structures are relatively stable in the long-term, which discounts the considerable, short-term changes in ties and node involvement often found in practice (Kossinets and Watts 2006). However, over the past two decades, there has been an increasing emphasis on longitudinal methods, specifically in the fields of organizational behavior and team science, to understand network evolution. These types of studies reveal new insights about many types of networks, including coordination networks following hazard events (Opdyke et al. 2016). Second, few studies adequately define and operationalize resilience outside of civil, infrastructure and other types of physical systems. The concept of resilience in physical systems is well-established, where performance can be expressed as a percentage of their static design capacity (e.g. kilowatts generated, customers served) at any given time. Resilience to a disruptive event is thus mathematically defined as the normalized integral of the performance function taken between the time of the event and the time of full system recovery (Bruneau et al. 2003). However, for social systems with dynamic capacities, such as the communication networks found in AEC project teams, performance must be expressed and measured differently to derive a meaningful operationalization of resilience. Lastly, prior research does not focus on identifying the underlying mechanisms of action, such as the information processing process, for how resilience in communication networks lead to desirable project outcomes.

Going forward, we intend to test the conceptual framework in assessing resilience by conducting a pilot case study that tracks the structure of an active AEC team's communication network and their associated communication outcomes over the project duration. We believe that email messages between individual team members may be used to construct directed, longitudinal communication networks of the project team. Tie strength in these could then be defined as the number of messages sent from one team member to another within any desired period. In this manner, changes in global-level properties of the communication network on a project, such as density and centralization, can be examined for a relationship with compositional and role change events occurring within the AEC team. These network properties could also be examined alongside communication outcomes, which could include percent plan complete (PPC) from the use of the Last Planner System or response latency. Both outcomes are indicative of the effectiveness of the team's communication network, which is necessary to quantitatively assess the rapidity and robustness dimensions of resilience for a given disruption. More qualitative methods, such as network ethnography would be necessary to understand the redundancy of the network, as well as the resourcefulness displayed by the AEC team during the recovery period.

CONCLUSIONS

By presenting a conceptual framework, this paper provides new insights into how resilience of communication networks may be studied and applied in AEC teams. A better understanding of the process influencing resilience in communication networks can improve the work flow, coordination and efficiency of information exchanges on complex, construction and engineering projects. By linking patterns in team composition, communication network structure and resilience with project outcomes (e.g. budget and schedule), there are implications for predicting performance based on the how the network evolves. The predictive capacity offered by this research can make project teams more agile in responding to both internal and external disruptions. For example, we can better understand the attributes and role structures needed to replace a departing team member to maintain network functionality, or we can consider big data analysis of communication network vulnerabilities, such as the identification of overly connected team members whose departure would severely reduce project performance. Thus, this research has the potential to inform the formation and management of more resilient communication networks in AEC teams.

References

Balkundi, P., Kilduff, M., Barsness, Z. I., & Michael, J. H. (2007). Demographic antecedents and performance consequences of structural holes in work teams. *Journal of Organizational Behavior*, *28*(2), 241-260.

Benson, J. K. (1975). The interorganizational network as a political economy. *Administrative science quarterly*, 229-249.

Berggren, C. Soderlund, J. and Anderson, C. (2001). Clients, contractors, and consultants: the consequences of organizational fragmentation in contemporary project environments. *Project Management Journal*, 32(3), 39-48.

Bowen, P. A., and Edwards, P. J. (1996). Interpersonal communication in cost planning during the building design phase. *Construction Management & Economics*, *14*(5), 395-404.

Briscoe, G. (2005). Women and minority groups in UK construction: recent trends. *Construction Management and Economics*, *23*(10), 1001-1005.

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W.A. and von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra*, 19(4), 733-752.

Cherns, A. and Bryant, D. (1983). Studying the client's role in construction management. *Construction Management and Economics*, 2(2), 177-184.

Chua, D. K. H., Kog, Y. C., and Loh, P. K. (1999). Critical success factors for different project objectives. *Journal of construction engineering and management*, *125*(3), 142-150.

Cimellaro, G. P., Reinhorn, A. M., and Bruneau, M. (2010). Framework for analytical quantification of disaster resilience. *Engineering Structures*, *32*(11), 3639-3649.

Cummings, J. N., and Cross, R. (2003). Structural properties of work groups and their consequences for performance. *Social networks*, *25*(3), 197-210.

Dainty, A. R., Millett, S. J., and Briscoe, G. H. (2001). New perspectives on construction supply chain integration. *Supply chain management: An international journal*, 6(4), 163-173.

Devine, D.J., and Philips, J.L. (2001). Do smart teams do better: A meta-analysis of cognitive ability and team performance. *Small Group Research*, 32: 507-532.

Di Marco, M. K., and Taylor, J. E. (2011). The impact of cultural boundary spanners on global project network performance. *The Engineering Project Organization Journal*, *1*(1), 27-39.

Eccles, R.G. (1981). The quasifirms in the construction industry. *Journal of Economic Behavior and Organization* (2), 335-357.

Egan, J. (1998). *Rethinking Construction*, London: DETR/Stationery Office.

El Asmar, M., Hanna, A. S., and Loh, W. Y. (2013). Quantifying performance for the integrated project delivery system as compared to established delivery systems. *Journal of Construction Engineering and Management*, 139(11), 04013012.

Franz, B., Leicht, R., Molenaar, K. and Messner, J. (2017). Impact of team integration and group cohesion on project delivery performance. *Journal of Construction Engineering and Management*, DOI: 10.1061/(ASCE)CO.1943-7862.0001219.

Gunderson, L. H. (2000). Ecological resilience--in theory and application. *Annual review of ecology and systematics*, 425-439.
Heider, F. (1958). *The Psychology of Interpersonal Relations*. New York: Wiley.
Henisz, W.J., Levitt, R.E. and Scott, R. (2012). Toward a unified theory of project governance: Economic, sociological and psychological supports for relational contracting. *The Engineering Project Organizations Journal*, 2(1-2), 37-55.
Horwitz, S. K., and Horwitz, I. B. (2007). The effects of team diversity on team outcomes: A meta-analytic review of team demography. *Journal of management*, *33*(6), 987-1015.
Javernick-Will, A. N., and Scott, W. R. (2010). Who needs to know what? Institutional knowledge and global projects. *Journal of Construction Engineering and Management*, *136*(5), 546-557.
Jin, Y., and Levitt, R. E. (1996). The virtual design team: A computational model of project organizations. *Computational & Mathematical Organization Theory*, 2(3), 171–195.
Konchar, M. and Sanvido, V. (1998). Comparison of US project delivery systems. *Journal of Construction Engineering and Management*, 124(6), 435-444.
Kossinets, G., and Watts, D. J. (2006). Empirical analysis of an evolving social network. S*cience*, *311*(5757), 88-90.
Lahdenperä, P. (2012). Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. *Construction Management and Economics*, 30(1), 57-79.
Larson, A. (1992). Network dyads in entrepreneurial settings: a study of the governance of exchange relationships. *Administrative Science Quarterly*, Vol. 37, pp.76-104.
Latham, S. M. (1994). *Constructing the Team*. London: HM Stationery Office.
Lau, D. C., and Murnighan, J. K. (1998). Demographic diversity and faultlines: The compositional dynamics of organizational groups. *Academy of Management Review*, *23*(2), 325-340.
Macomber, H., and Howell, G. (2003). Linguistic action: Contributing to the theory of lean construction. In *Proceedings of the 11th Annual Meeting of the International Group for Lean Construction* (pp. 1-10).
Manyena, S. B. (2006). The concept of resilience revisited. *Disasters*, *30*(4), 434-450.
Masten, A. S. (2001). Ordinary magic: Resilience processes in development. *American Psychologist*, *56*, 227.
McPherson, J. M., and Smith-Lovin, L. (1987). Homophily in voluntary organizations: Status distance and the composition of face-to-face groups. *American Sociological Review*, 370-379.
Menches, C. L., and Abraham, D. M. (2007). Women in construction—tapping the untapped resource to meet future demands. *Journal of Construction Engineering and Management*, *133*(9), 701-707.
Mizruchi, M. S. (1996). What do interlocks do? An analysis, critique, and assessment of research on interlocking directorates. *Annual Review of Sociology*, 271-298.
Mollaoglu-Korkmaz, S., Swarup, L., and Riley, D. (2011). Delivering sustainable, high-performance buildings: Influence of project delivery methods on integration and project outcomes. *Journal of Management in Engineering*, 29(1), 71-78.

Monge, P. R., and Contractor, N. (2003). *Theories of Communication Networks*. New York: Oxford University Press

Newman, M. E., Forrest, S., and Balthrop, J. (2002). Email networks and the spread of computer viruses. *Physical Review E*, *66*(3), 035101.

Opdyke, A., Lepropre, F., Javernick-Will, A., and Koschmann, M. (2016). Inter-organizational resource coordination in post-disaster infrastructure recovery. *Construction Management and Economics*, 1-17.

Park, J., Seager, T. P., Rao, P. S. C., Convertino, M., and Linkov, I. (2013). Integrating risk and resilience approaches to catastrophe management in engineering systems. *Risk Analysis*, 33(3), 356-367.

Parker, S. K., and Skitmore, M. (2005). Project management turnover: causes and effects on project performance. *International Journal of Project Management*, *23*(3), 205-214.

Phua, F. T., and Rowlinson, S. (2004). How important is cooperation to construction project success? A grounded empirical quantification. *Engineering, Construction and Architectural Management*, *11*(1), 45-54.

Provan, K. G., and Milward, H. B. (1995). A preliminary theory of interorganizational network effectiveness: A comparative study of four community mental health systems. *Administrative science quarterly*, 1-33.

Raiden, A. B., Dainty, A. R., and Neale, R. H. (2004). Current barriers and possible solutions to effective project team formation and deployment within a large construction organization. *International Journal of Project Management*, 22(4), 309-316.

Sambasivan, M. and Soon, Y. W. (2007). Causes and effects of delays in Malaysian construction industry. *International Journal of project management*, 25(5), 517-526.

Sasovova, Z., Mehra, A., Borgatti, S. P., and Schippers, M. C. (2010). Network churn: The effects of self-monitoring personality on brokerage dynamics. *Administrative Science Quarterly*, *55*(4), 639-670.

Settoon, R. P., Bennett, N., and Liden, R. C. (1996). Social exchange in organizations: Perceived organizational support, leader–member exchange, and employee reciprocity. *Journal of Applied Psychology*, 81(3), 219.

Sherif, M. (1958). Superordinate goals in the reduction of inter-group conflicts. *American Journal of Sociology*, 63, 349-356.

Stewart, G. (2006). A meta-analytic review of relationships between team design features and team performance. *Journal of Management*, 32: 29-54.

Thietart, R. and Forgues, B. (1995). Chaos theory and organizations. *Organization Science*, 6(1), 19-31.

Walker, B., Holling, C. S., Carpenter, S. R., and Kinzig, A. (2004). Resilience, adaptability and transformability in social--ecological systems. *Ecology and society*, *9*(2), 5.

Whitley, R. (2006). Project-based firms: new organizational form or variations on a theme? *Industrial and Corporate Change*, 15(1), 77-99.

Wolf, T., Schroter, A., Damian, D., and Nguyen, T. (2009, May). Predicting build failures using social network analysis on developer communication. In *Proceedings of the 31st International Conference on Software Engineering* (pp. 1-11). IEEE Computer Society.

Youssef, C. M., and Luthans, F. (2007). Positive organizational behavior in the workplace the impact of hope, optimism, and resilience. *Journal of Management*, *33*, 774-800.

Zaheer, A., & Bell, G. G. (2005). Benefiting from network position: firm capabilities, structural holes, and performance. *Strategic Management Journal*, *26*(9), 809-825.