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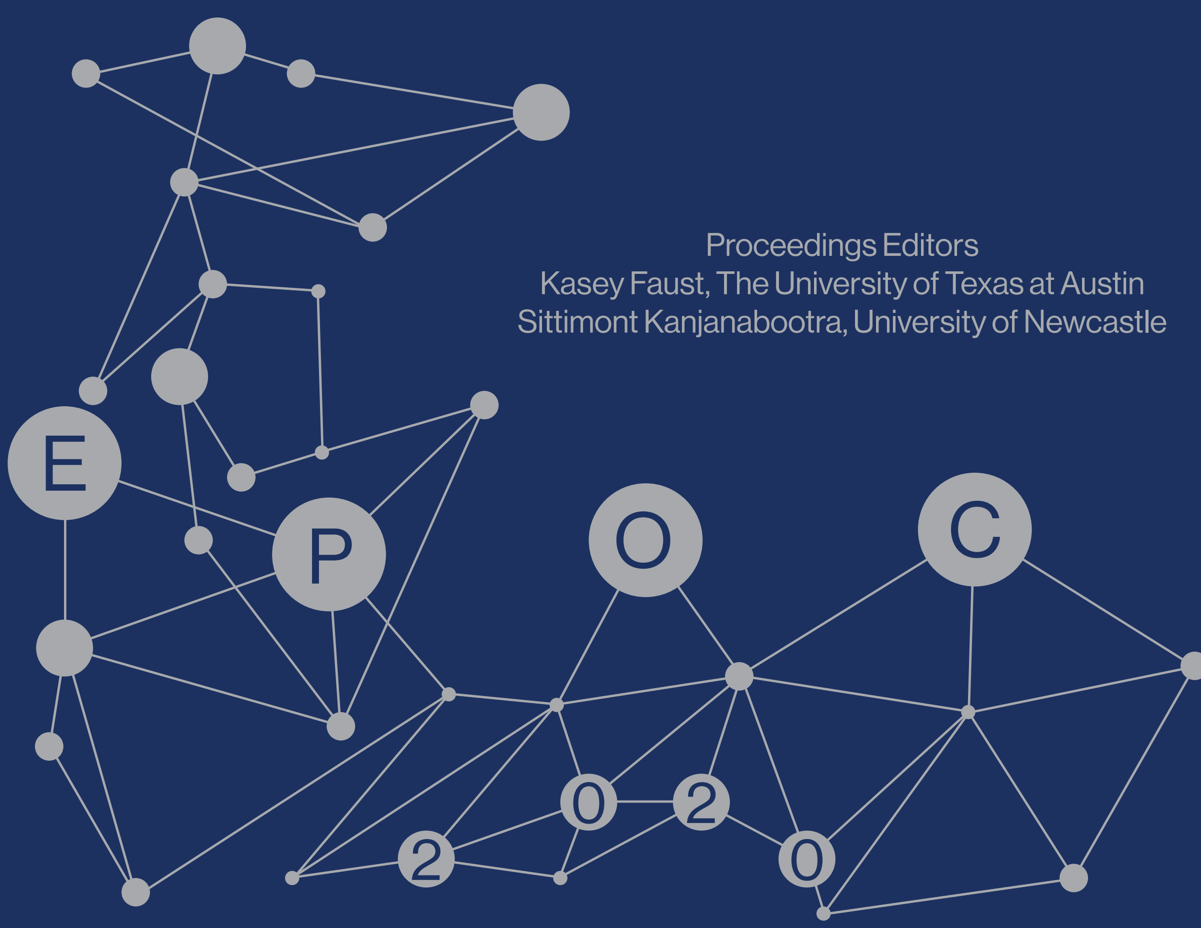


EXPERTISE FLOWS IN AEC PROJECTS: AN ANALYSIS OF MULTI-LEVEL TEAMS FOR SUSTAINABILITY

Meltem DUVA, Sinem MOLLAOGLU, Dong ZHAO, and Kenneth A. FRANK

ABSTRACT

Architectural, Engineering, and Construction (AEC) project teams adopt different methods to facilitate collaboration to achieve sustainability goals, which requires a high level of expertise integration. Tracking expertise flows in interdisciplinary and inter-organizational project networks is challenging because of the unique project nature, fluid expertise boundaries, and varying project requirements. It can be even more difficult considering sustainability outcomes, due to the need for high-level expertise integration. Social network approach addresses the integration and information flow dynamics. However, there is a knowledge gap regarding what network characteristics are favorable for improved sustainability outcomes in AEC projects, how they evolve during delivery, and how relevant expertise flows through project networks. To respond to the need in the literature, this study aims to develop a holistic understanding of AEC project team networks and associated characteristics that allow experts to exchange knowledge to optimize sustainability outcomes for built environment projects. We longitudinally collected e-mail exchange, observational, and archival data during the design phase of an AEC case study project and performed Social Network Analysis (SNA) bolstered by mixed methods. Results suggest that network topology matters for AEC project teams. In other words, understanding the interactions between components of a network (e.g., expertise areas represented and distributed in the network and the number of boundary spanners) is as important as the network parameters for better sustainability outcomes.

KEYWORDS

Social Network Analysis, Project Networks, and Sustainability.

INTRODUCTION

Environmental problems have drastically increased over the years due to increasing human population and depletion of the energy, material, and water resources (LEED 2016). Buildings consume 72% of the electricity in the U.S. and 40% of raw materials globally and significantly contribute to this problem (Outlook 2010). Moreover, due to technological developments, building functions become more complex, making buildings the biggest energy consumers (Cao et al. 2016). With the increased consumption of resources and energy, there is a demand for built environment projects to be sustainable and especially energy efficient.

The unique nature of sustainable built environment projects is that they require a high level of expertise integration and collaboration to optimize systems and performance (Korkmaz et al. 2010; Rohracher 2001). The literature has focused on the following aspects to achieve team integration in the past decade: (a) organizational metrics with project delivery methods such as the timing of involvement and owner commitment

(Bilec and Ries 2007; Mollaoglu-Korkmaz et al. 2013), (b) knowledge transfer practices (Garciacortes 2017; Schröpfer et al. 2017), and (c) information technologies to foster collaboration (Al Hattab and Hamzeh 2018; Du et al. 2020).

Social network approach (Chinowsky et al. 2008) has been gaining attention in the AEC literature to evaluate integration and collaboration in project teams. By using social networks, individuals' (nodes) interaction patterns (ties) can be visualized and mathematically assessed (Hanneman and Riddle 2005). Moreover, social networks can be used to accelerate behavioral changes, improve organizational efficiency, and improve diffusion of innovation (Spinks 2011; Valente 2012). However, for complex interdisciplinary and inter-organizational project teams team such as those in the AEC industry, evaluating the social networks based solely on the organizational structure is not adequate to understand the expertise flow patterns (Cross et al. 2002). Thus, multi-level analysis of network topology (e.g., across individual, sub-team, and team levels) (Foss et al. 2010) is necessary to diagnose challenges and promote organizational efficiency (Garciacortes 2017).

This study aims to develop a holistic understanding of AEC project team networks and associated characteristics that allows experts to exchange knowledge that can be used to optimize sustainability outcomes for built environment projects. In pursuit of this goal, the study explored the social network characteristics of an AEC project team that facilitate expertise flow for optimal sustainability outcomes. We longitudinally collected e-mail exchange, observational, and archival data during the design phase of an AEC case study project and performed Social Network Analysis (SNA) and other quantitative and qualitative analyses with a focus on Energy and Atmosphere (EA) issues to evaluate sustainability outcomes. The results revealed insights into network characteristics such as position of certain expertise areas in the network along with key SNA parameters, and the importance of network topology (i.e., both the evaluation of node distribution and characteristics across the network and SNA parameters) for expertise flows in the context of sustainability (Boccaletti et al. 2006).

LITERATURE REVIEW

Due to the intrinsic characteristics of green buildings, there is a need for a high level of expertise integration and collaboration in their delivery (Korkmaz et al. 2010; Rohracher 2001). However, AEC inter-organizational project teams consist of individuals with little or no previous connections that are expected to collaborate. Moreover, construction teams are dynamic and evolutionary over the course of projects as different individuals and companies come and go based on the project needs and schedule (Lin 2015). These obstacles create fragmented teams and increase integration problems failing to achieve project goals including sustainability.

Enhanced project outcomes require team members to continuously exchange knowledge and collaborate efficiently (Chinowsky et al. 2008). Therefore, to achieve enhanced sustainability outcomes, the project networks must be studied based on a social collaboration perspective (Chinowsky et al. 2008).

Via using Social Network Analysis (SNA), team characteristics and interactions can be mapped, visualized as sociograms, and assessed mathematically by using the network parameters. The literature offers parameters to evaluate and interpret the structural properties of AEC project networks, such as density, degree, triadic closure, structural holes, and tie strength, which have been reported to influence sustainability outcomes if they have trust and reciprocity among actors as seen in Table 1 (Henry and Vollan 2014).

Table 1. Network Parameters, Definitions, and Use in the Context of Sustainability

Network Parameter	Definition	The use
Density	Density is a measure of whole network and calculated by dividing the number of existing ties by the number of all possible ties.	Higher density might enhance sustainability outcomes as there is more interaction and information exchange between actors (Henry and Vollan 2014). However, sparse networks can improve absorptive capacity of network and information diversity (Schröpfer et al. 2017).
Degree	Degree of a node is the number of other nodes linked to it (Freeman 1978).	The actors with a higher degree can control the information flow in the networks and help spread innovations (Henry and Vollan 2014).
Triadic Closure	If A-B and A-C nodes in a network have a relationship, B-C will also likely have at least a weak tie (Granovetter 1973).	Triadic closure in networks strengthens trust and therefore has the potential to improve collective action and sustainability outcomes (Henry and Vollan 2014).
Strength of a Tie	Strength of a tie is the “combination of the amount of time, the emotional intensity, the intimacy and the reciprocal services” in a network between nodes (Granovetter 1973).	Weak ties become important when they connect people from different social circles, promote the flow of novel information, and create bridges among clusters that are otherwise disconnected (Granovetter 1973).
Structural holes	Structural holes in a network are based on a gap between two nodes or groups (Ronald S. Burt 2004). To convey the information between the fragmented parts of the networks, the people positioned as brokers are called bridges (Hargadon and Sutton 1997).	A structural hole creates a fragmented structure and on the different sides of the hole the nodes generate different expertise flow (Hargadon and Sutton 1997).

Apart from the network parameters used to evaluate properties of network topology, understanding the topology of interactions between components of a network is important for better sustainability outcomes (Albert and Barabási 2002). Examining the way nodes are placed and interconnected might shed light on sustainability problems. For example, a lack of **expertise diversity** in networks might inhibit the ability to solve the sustainability problems (Henry and Vollan 2014) even if they have desirable parameters. Similarly, **boundary spanners** help to facilitate knowledge exchange interactions among team members in networks (Iorio et al. 2012). They bring external valuable information into their team and enhance the efficiency of knowledge exchange across roles and tiers, which is required for better outcomes (Cross and Prusak 2002).

Researchers have attempted to identify network characteristics for better project outcomes. Garcia et al. (2020) identified that networks including members with various expertise areas and engaging in triadic information sharing patterns increases productivity. Cummings and Cross (2003) presented that structural holes of the leaders' network and organizational networks reflecting the hierarchical structure negatively affect the performance. Marco et al. (2010) examined the collaboration in project networks and found out that the number of boundary spanners has a positive effect on team performance. Zaheer and Bell (2005) observed that structural holes in the network positively affect the performance as they prevent unnecessary and repetitive information, and confirmed the results by Ronald S. Burt (2004).

As seen in the previous studies, the impact of the structural properties on outcomes depends on the desired function of the network, network resources flowing in the network, context and priorities (Henry and Vollan 2014). Therefore, there is a need for holistic evaluations and understanding of complex, multi-level AEC project networks utilizing longitudinal and in-depth reviews of network topology. We extend the previous studies by holistically examining complex interdisciplinary and inter-organizational project teams at multi-levels, especially in the AEC industry of which the product is unique and the requirements are different every time a new project team is formed (Cross et al. 2002) and in the context of sustainability. Therefore, our research question (RQ) is as follows:

> RQ: What are the network characteristics that allow experts to exchange knowledge to optimize sustainability outcomes for AEC projects?

METHODS

Data Collection

This paper stands as the first part of a longitudinal study focusing on a $20 million institutional renovation project delivered via construction management at risk. The project started in September 2018 and is planned to run for two years. The project team information exchange network included about 400 individuals with various levels of backgrounds and expertise, representing owner, designer, and general contractor roles, from 20 different organizations during the design phase (i.e., Schematic Design (SD), Design Development (DD) and Construction Documents (CD)). According to the selected institution's construction guidelines, all new construction and major renovation projects are to be Leadership in Energy and Environmental Design (LEED) certifiable.

In this paper, we focused on the design phase, where most crucial decisions with the highest impact on construction execution and building outcomes occur (AIA (The American Institute of Architects) 2007); and conducted two levels of analysis: whole project team and sub-team relating to Energy and Atmosphere (EA) issues of the project. According to LEED checklists, Energy and Atmosphere is the most important category based on the highest possible points (i.e. 33 points out of 110) among the eight categories (i.e. Location and Transportation, Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, Innovation and Regional Priority) (LEED 2016). Sustainability outcomes of the project were evaluated focusing on the EA issues in the project and how they got resolved over time.

We longitudinally collected e-mail exchange, observational, and archival data (i.e., meeting minutes and project documents shared with all project team members on web-based platforms). E-mail exchange data for the whole project network were collected via collaborative efforts with the project's leading participants (i.e., owner, designer, and contractor) and consisted of headers (i.e., sender, receiver, time, and subject). This data was used to calculate the edges and their strengths between the nodes in sociograms. E-mail subject line helped us to filter out the non-project specific emails among project members. According to the literature, using email data is an effective method to visualize and analyze AEC project networks (Dogan et al. 2015; Franz et al. 2018) and email data are representative of team interactions. To improve reliability, we interviewed with project participants and verified that the sociograms developed are representative of their communication patterns. Two coders from our research team observed the weekly project team meetings (i.e., 32 meetings during the design phase) and recorded the number of "information given" by each individual (Frank and Zhao 2005) to size the nodes in sociograms. To ensure reliability, coders met after the meetings to compare and merge their notes. Second, we calculated the rank Spearman correlation between coders to ensure inter-coder reliability. The average correlation was $r = 0.89$, $p < .01$, showing a highly similar trend between the coders. Archival data were used to create a timeline for data analyses, determine the EA sub-team members, and evaluate the sustainability outcomes.

Data Analysis

We analyzed archival documents to determine the project's progress loops (Garcia et al. 2014; Marks et al. 2001). SD, DD, and CD episodes in the design phase were further broken down into monthly time intervals based on the project progress (i.e., analyses showed cost growth and scope revisions as the key metrics to determine progress loops during the design phase). In total, the design phase consisted of seven intervals of approximately one month each (i.e., three in SD, two in DD, and two in CD). There were three days overlap between CD end and construction phase start. Archival documents also aided productivity calculations, which were used as a measure of sustainability outcomes. Using project meeting minutes, we created a Gantt chart to track EA issues over time and calculated EA team productivity using the percentage of total project issues resolved out of on-going ones in a given time interval as a measure of sustainability

To determine nodes for EA sub-network, we examined: 1) LEED guidelines and determined the roles and expertise areas to ideally collaborate for optimized EA outcomes (e.g., mechanical engineer, occupants, and commissioning authority); 2) project owner's LEED guidelines to determine targeted EA credits and responsible parties; and 3) the archival and email data to identify project issues and interactions related to those credits. Accordingly, 74 individuals out of 400 were included in the EA analyses.

Using email-exchange data as inputs for SNA, we drew sociograms for each interval for all team and EA sub-network members. To determine the strength of ties between nodes, we assigned 3, 2, and 1 as weights for daily, weekly, monthly communication, respectively. We coded individuals according to: (1) Main roles in the project (i.e., owner, designer, contractor); (2) tiers of decision-making and operation (Mollaoglu-Korkmaz et al. 2014) and (3) expertise areas such as organizational planning and programming, project planning, project needs and program, management, architectural design, civil engineering, mechanical, electrical and Mechanical, Electrical, Plumbing (MEP) construction (Garcia et al. 2020). We drew sociograms in Gephi. Observational data were used as an input for SNA node sizing (i.e., give information during project team meetings).

RESULTS

Figure 1 depicts the collaboration networks for the whole and the EA sub-team for seven consecutive intervals drawn with Gephi and arranged based on team members' attributes (i.e. role, tier, expertise). There are two main observations when we compare the networks. First, while the non-EA tier 2 and 3 members communicated with other roles through tier 1 members in their role, EA team members behaved as boundary spanners. Non-EA members in tiers 2 and 3 barely exchanged information if they belong to different roles and followed the hierarchical information exchange patterns.

Second, the EA team included project team leads from Tier 1 of different roles. They functioned as bridges between different roles and had stronger ties with their EA peers and the rest of the network. Furthermore, most of the expertise flow on the entire network was carried out by EA team members. Moreover, they have bigger nodes indicating that they have given more information and been more effective during the face-to-face project team meetings.

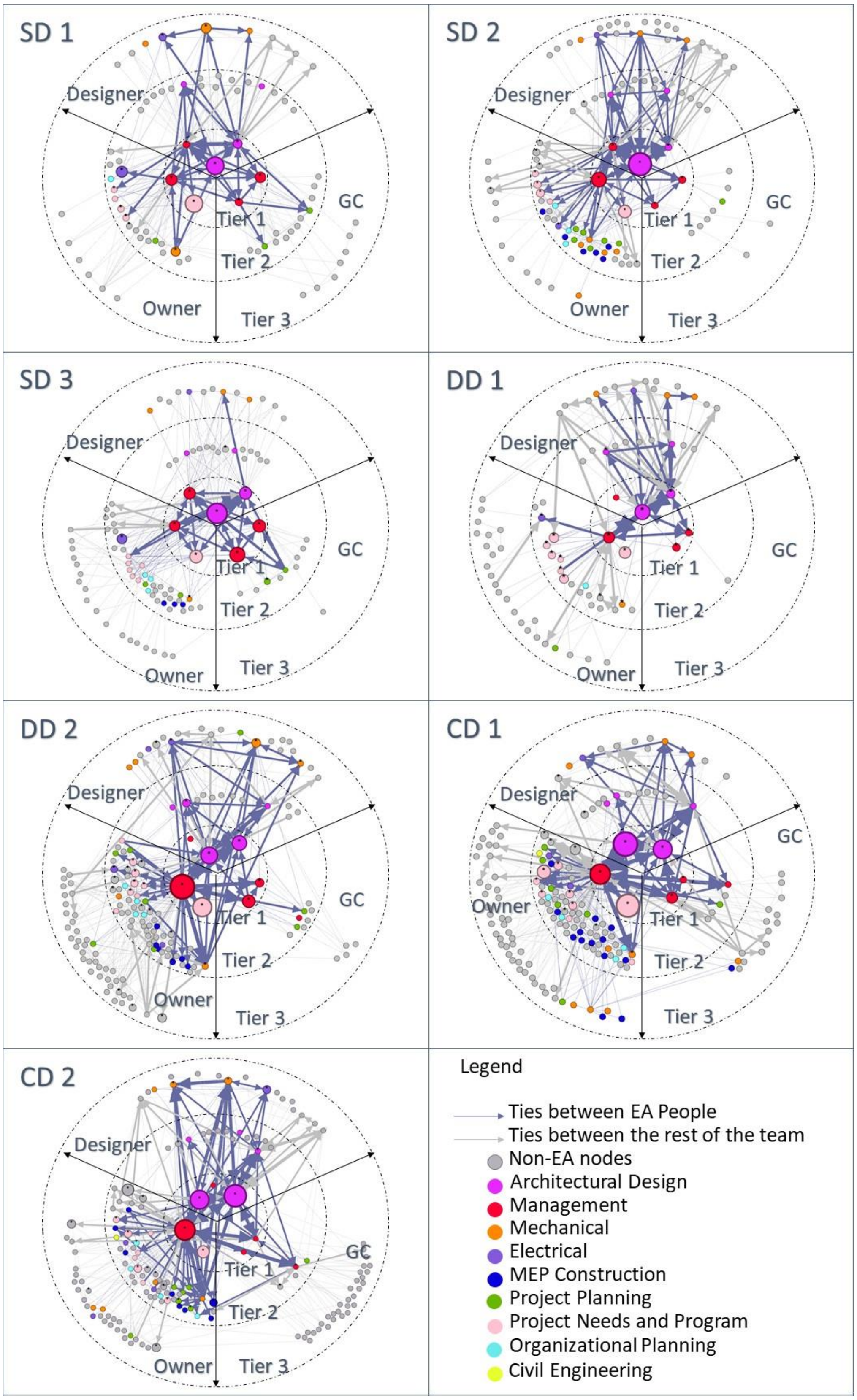


Figure 1. Sociograms of Project Communication Network Displaying Expertise Flows and Network Topology

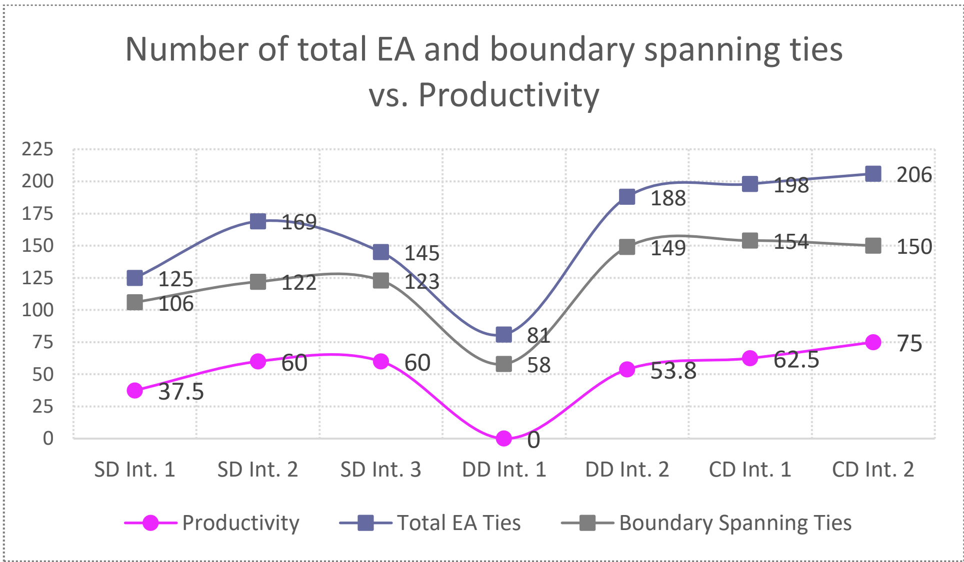
To evaluate the EA networks at the sub-team level, we first calculated the productivity as a measure of sustainability outcomes. Table 2 presents productivity outcomes of EA team throughout the design phase, where Construction Documents- Interval 2 has the highest productivity.

Table 2. Energy and Atmosphere (EA) Sub-team Productivity

	Intervals						
Issue Resolution	SD Int 1	SD Int 2	SD Int 3	DD Int 1	DD Int 2	CD Int 1	CD Int 2
# of Total Issues	8	10	5	5	13	7	4
# of Issues Resolved	3	6	3	0	7	4	3
Productivity (%)	37.5	60	60	0	53.8	62.5	75

Note: SD: Schematic Design, DD: Design Development, CD Construction Documents, Int: Interval

SNA delivered several observations for the EA team. First, when we calculate the expertise flow through total EA information exchange based on the number of ties in EA networks (without including tie strength), we noticed that there is a similar trend between expertise flow and productivity (Correlation coefficient 0.91) (Figure 2). When EA expertise flow was the highest during the seventh interval, the productivity was at its highest. Similarly, the number of boundary spanning ties (e.g., ties across roles and tiers) correlates with EA productivity (Correlation coefficient 0.92). Expertise flow and boundary spanner effect could have helped improve integration and problem-solving capacity by bringing the timely and novel input.



SD: Schematic Design, DD: Design Development, CD Construction Documents, Int: Interval

Figure 2. Number of Total Energy & Atmosphere (EA) and Boundary Spanning Ties vs. EA Productivity Across Time Intervals During Phases of Design

Two other observations transpired from these analyses are included: (1) There is a similar trend between the productivity and the number of EA experts in the networks (Correlation coefficient 0.74). Table 3 shows the number of experts involved in the networks. During the CD interval 1 and 2, networks had the biggest number of experts from 9 different expertise areas and productivity was highest during these intervals.

Similarly, the least expertise diversity and number of experts existed in the DD interval 1, where productivity was the lowest.

Table 3: Number of Experts Involved in EA Sub-team Sociograms

	Intervals						
Expertise Area	SD Int 1	SD Int 2	SD Int 3	DD Int 1	DD Int 2	CD Int 1	CD Int 2
Architectural Design	4	4	4	4	5	5	5
Management	4	4	4	4	5	4	5
Project Needs and Program	5	5	7	7	9	9	9
Mechanical	4	8	4	4	6	9	7
Electrical	2	2	2	2	4	3	4
MEP Construction	–	6	3	–	6	14	8
Project Planning	3	7	4	1	8	7	7
Organizational Planning	1	3	3	1	4	4	4
Civil Engineering	–	–	–	–	–	1	1
Total Number of Experts	23	39	31	23	47	56	50

Note: Number of Experts: Total number of individuals from EA team in sociograms for each interval

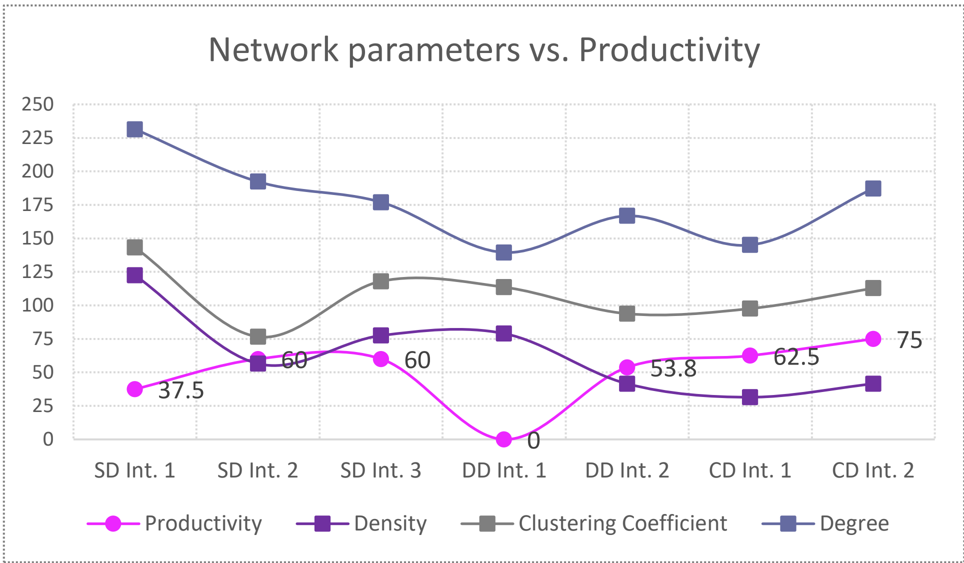
(2) Information given by the EA experts during the weekly face-to-face meetings showed a moderate relationship with the productivity as seen in Table 4 (Correlation coefficient 0.57). During DD interval 1, the least amount of information given by the individuals attending the weekly project team meetings. Architectural design, management, project needs and program, mechanical and electrical expertise areas were consistently represented in the meetings. The people with MEP construction, project planning, organizational planning and civil engineering expertise areas attended the meetings based on the needs of the project. Overall, expertise diversity and boundary spanner effect could have helped improve integration and collaboration within the team. Especially, during the CD interval 2, bringing in the different expertise to the network, such as civil engineering, not only via email communication but also in the face-to-face meetings had a direct impact on the productivity.

Table 4: Information Given During the Face to Face Meetings by Expertise Area

	Intervals						
Expertise Area	SD Int 1	SD Int 2	SD Int 3	DD Int 1	DD Int 2	CD Int 1	CD Int 2
Architectural Design	138	189	203	125	258	516	415
Management	121	143	266	84	324	324	201
Project Needs and Program	124	129	70	172	229	540	195
Mechanical	71	–	16	1	51	7	42
Electrical	67	4	43	9	19	–	40
MEP Construction	–	–	–	–	5	–	36
Project Planning	–	–	9	–	–	–	10
Organizational Planning	–	–	–	–	–	–	9
Civil Engineering	–	–	–	–	–	–	–
Total Cumulative Info Given	521	465	607	391	886	1387	948

Note: Total Cumulative Info Given: Total number of the information given by the individuals from EA team in the project meetings.

When we evaluate the structural properties of the networks using network parameters (i.e., density, average degree, and clustering coefficient), we did not observe similar trends with EA productivity (Figure 3). The correlation coefficients between productivity-density, productivity-clustering coefficient, and productivity-average degree were -0.53, -0.31, 0.25, respectively. Network properties did not reflect the needs of the network within the context of sustainability. Therefore, it was not clear how they could have influenced team productivity throughout the design phase.



SD: Schematic Design, DD: Design Development, CD Construction Documents, Int: Interval
(Note: The values for networks parameters were normalized to illustrate the relationship better)

Figure 3. Network Parameters vs. EA Productivity Across Time Intervals During Phases of Design

In summary, results showed that EA team, as bridges, facilitated expertise flow by exchanging information. The highest productivity occurred when team members from different roles, tiers, and expertise areas exchanged information via email and during the face-to-face team meetings. Boundary spanners had an important effect on team productivity by bridging the clusters and facilitating the novel, necessary, and timely information flow. Lastly, the network parameters did not show similar trends with productivity.

DISCUSSIONS

The results showed that except for the network parameters, evaluation of the interaction topology and identities of the interrelated network members are crucial for better sustainability outcomes. The amount of information exchange and the number of boundary spanning ties had a direct effect on productivity. The effect of boundary spanners can be explained by the timely and novel input they brought in. Our research confirms prior research by Marco et al. (2010) that presents boundary spanners resolve conflicts and increase collaboration effectiveness and therefore, team performance.

The impact of the network parameters on sustainability outcomes depends on the desired function of the network, resources flowing and priorities (Henry and Vollan 2014). There was almost an inverse relationship between the EA productivity and network density, and productivity and clustering coefficient. Even though the higher network density might indicate more knowledge transfer, it might increase the inefficiency and reduce the absorptive capacity (Schröpfer et al. 2017). Therefore, by reducing the density, structural holes might help mitigate repetitive information (Ronald S. Burt 2004). Similarly, even though triadic closure might improve trust between nodes, it might inhibit nodes to access novel information and can have an adverse effect on sustainability outcomes (Henry and Vollan 2014). For seven consecutive intervals, architectural design, management, project needs and program, mechanical and electrical expertise areas existed in the EA networks and project meetings consistently. These expertise areas provided most of the information given in the face to face meetings. MEP construction, project planning, organizational planning and civil engineering expertise came and went based on the project needs. However, whenever expertise areas existed in the networks and team meetings, productivity improved as a result of diverse and direct input.

The study findings above have important implications for interdisciplinary complex project teams and the project management discipline. First, we presented network parameters to evaluate expertise flows. We posit that focusing solely on network parameters is not enough for advanced sustainability outcomes. The structural properties of the networks might not necessarily reflect or fulfill the needs of the real networks (Boccaletti et al. 2006). Evaluating the topology of complex networks longitudinally would lead to a better understanding of collaboration and interaction patterns by focusing both its dynamical and mechanical behaviors (Boccaletti et al. 2006; Chinowsky et al. 2008). Briefly, evaluation of network topology by looking at the forces formed it, the way nodes are interconnected, positioned, and expertise diversity improves the sustainability outcomes. Network topology with boundary spanners and diverse expertise areas enhances the actions and abilities of the individuals by stimulating expertise flows. Therefore, project managers should stay active and oversee the integration of team members.

CONCLUSIONS

The goal of this research is to examine the characteristics of project networks and expertise flow patterns that allow experts to exchange knowledge that can be used to optimize sustainability outcomes. In pursuit of the goal, this study performed Social Network Analysis (SNA) and mixed methods of other quantitative and qualitative analyses with a focus on Energy and Atmosphere (EA) issues of an AEC project to evaluate sustainability outcomes. Our findings show that not only network parameters but also the evaluation of whole network topology is important to understand expertise flow and its effect on the sustainability outcomes.

The study showed the highest productivity when the EA networks included members from different key expertise areas (e.g. architectural design, project needs and program and civil engineering), and organizational roles (i.e. designer, owner, and general contractor) and shared information via email and in the face-to-face meetings.

Lessons learned of this study align with the literature and suggest that structural properties of the network may be far from the needs. Therefore, to fully understand the networks, context and dynamics of the networks should be considered longitudinally. From a practical standpoint, project managers should evaluate the overall network topology and keep necessary members in the networks for better collaboration.

The main limitation of this study is that the results were drawn from a single case study based on the analyses for the design phase and all information flows between any two network members were considered equal regardless of their role, tier or expertise areas. Nevertheless, the study provides SNA methods to improve sustainability that can be applied to networks in any complex project team. Future research should investigate the parameters studied herein throughout the latter phases project delivery and in project teams with different characteristics. Moreover, this study calculated the total EA expertise flow and boundary spanning ties based on the number of existing ties in the network. Future research should examine expertise exposure in the network by considering tie strength and expertise areas of the nominators.

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