Case Study

A Framework for Social Network Interventions in AEC Teams: Strategies and Implications

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Abstract: Successful execution of a project depends on efficient collaborations among a diverse set of actors and organizations. Establishing efficient collaboration networks is vital to channeling necessary expertise to achieve desirable outcomes. Network interventions describe the process of using network-supported strategies to enable knowledge sharing and coordination critical for network performance. However, there is a lack of intervention studies in the architectural, engineering, and construction (AEC) domain. To fill this gap in the literature, this study used social network analysis (SNA) and mixed methods to develop an intervention framework for AEC teams. The research team examined the performance and communication trends of an AEC project team during project delivery in light of the literature to inform network interventions. After vetting the developed strategies through interviews with select project leaders, interventions were presented to the whole project team for further verification and feedback. The results contribute to the body of knowledge by providing an intervention framework for AEC teams and implications for practitioners in selecting and assigning experts in key roles and positions in projects as well as managing team communications and networks in a dynamic manner during project delivery for improved team and project performance. **DOI: 10.1061/JCEMD4.COENG-13475.**

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Introduction

Architectural, engineering, and construction (AEC) teams consist of a wide range of experts, organizations, and stakeholders working under pressure to meet project specifications and client requirements. Successful execution of a project relies upon productive collaborations among experts from various disciplines (Cross et al. 2006; Duva et al. 2020). However, experts' abilities to successfully integrate their knowledge and skills frequently encounter challenges due to the complex features of AEC projects (Korkmaz and Singh 2012).

To eliminate the challenges of complexity, social network analysis (SNA) emerged as a robust tool to depict and systematically assess the topology of interactions in AEC collaboration networks (Hanneman and Riddle 2005; Kereri and Harper 2018). More importantly, SNA can help identify constraints in collaboration networks, find appropriate solutions at critical points to mitigate fragmentation problems (Lin 2015), and improve knowledge transfers and project performance by using network interventions (Cross et al. 2002).

Formally, the network intervention term describes the use of SNA-driven strategies to generate social influence, facilitate behavior change, and improve performance (Valente 2012) by improving network effectiveness (Cross et al. 2006). However, there is a lack of intervention studies that can help improve the functioning of project team networks.

To fill this gap in the literature, this paper studied the network intervention phenomenon in the context of AEC project team networks via the lens of Cross et al.'s (2006) framework to understand the functioning and needs of AEC project team networks. Specifically, the objective of this study was to develop an intervention framework by observing and leveraging an in-depth case study in light of the recent AEC literature to improve knowledge transfers and collaboration in AEC teams for better team and project performance. The study contributes to the literature by providing an intervention framework to help improve system functioning based on evolving project needs pertaining to making personnel assignments, tracking overload, increasing engagement, and addressing fragmentation problems within AEC project teams.

Literature Review

Social Network Analysis and Interventions

SNA is the method of assessment and calculation of relational and social structures (Butts 2008). The smallest network consists of two individuals (hereafter referred to as nodes) and one relationship (hereafter referred to as ties) connecting them. Bigger networks can be studied through sociograms, in which relationship schemes of individuals in a network are visualized.

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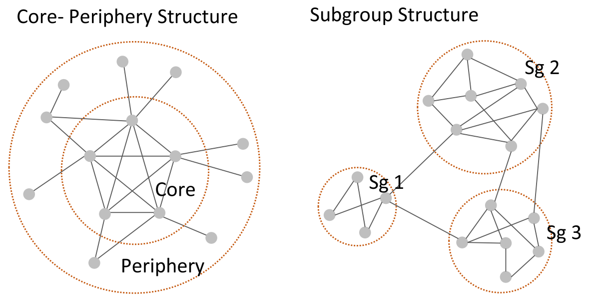

Fig. 1. Core–periphery and subgroup (Sg) structure.

SNA is also helpful in determining actionable points in networks and operationalizing collaborative patterns (Maya-Jariego and Holgado 2015), namely network interventions. Network interventions indicate a series of systematic efforts designed to enhance knowledge sharing and coordination to achieve improved performance and desirable outcomes in social systems (Valente 2012). Network configurations and metrics identified using SNA can inform interventions (Frank et al. 2022).

Network configurations such as core–periphery and subgroup structures emerge according to communication patterns, and serve different purposes in networks (Fig. 1). In a core–periphery structure, the core consists of a small number of members who interact frequently, whereas the periphery includes members who have limited connections which are primarily to the core (Borgatti and Everett 2000). A member is more (core) or less (periphery) central to the network based on their interactions with other team members. A subgroup structure represents the existence of densely connected groups of individuals that have only sparser connections between groups (Frank 1995). Additionally, network metrics help mathematically evaluate network configurations, overall team collaboration, and individuals' roles and leadership positions in networks. Objective evaluation of network configurations and network metrics such as density and cohesion at the team level and degree and betweenness centrality at the individual level (and evolutions thereof) can provide basis interventions (Cross et al. 2008) in pursuit of improved collaboration networks and performance.

According to Cross et al. (2006), assessing the following can guide network interventions: (1) identifying central people in networks to balance communication and information overload; (2) finding brokers to help diffuse knowledge; (3) including key peripheral players to integrate their unique expertise and skills; (4) targeting fragmented points in the networks to fill structural holes; and (5) improving external connectivity by activating boundary spanners. Building upon Cross et al. (2006), Valente (2012) categorized network interventions targeting: (1) individuals, i.e., empowering selected individuals as champions of behavioral changes; (2) segmentation, i.e., focusing on a group of people to induce change at the same time; (3) induction, i.e., triggering peer-to-peer interaction to enhance information and behavioral diffusion focusing on existing nodes (e.g., individuals) and their ties (e.g., relationships); and (4) alteration, i.e., adding or deleting nodes in the network and rewiring ties between nodes to increase performance and efficiency.

Network Interventions in AEC Teams

SNA is a robust approach to visualize and assess interaction patterns of complex project teams (Lee et al. 2018). Consequently, network analysis has become of growing interest in the AEC domain in the last decade, particularly for the evaluation of team integration, communication, and knowledge sharing (Kereri and Harper 2018).

As one of the early pioneers of SNA studies in the AEC domain, Pryke (2004) stated that SNA is an important tool to examine project networks and degree centrality of project actors provides quantitative and qualitative understanding of their roles and power. Building upon Pryke (2004), centrality and network density measures were found to be suitable for analyzing project networks (Pryke 2005). Other than proposed network metrics that help evaluate network mechanics, underlying network dynamics, such as trust or shared values, also were found to be important for better project performance (Chinowsky et al. 2008). Lin (2015) defined three levels of network analysis to discover obstacles affecting network efficiency and resolve them: network topology, subnetworks, and individuals. Recent research produced many insights into AEC project team networks including inconsistencies between organizational and communication networks and how to address them (Zhao et al. 2021), the impact of network topology and metrics on performance (Duva et al. 2020), and the importance of triadic closures in network transitions (Garcia et al. 2021).

Although there is an exponential trend in the number of SNA studies in the AEC domain concerning project and team performance and effectiveness, intervention studies still are in their infancy (Kereri and Harper 2019). Chinowsky et al. (2011) demonstrated the early potential of network intervention in AEC teams, presenting a project network interdependency alignment approach to identify neglected and ineffective knowledge exchanges. Although this approach can help project managers proactively avoid such deficiencies, the study did not specify intervention strategies and protocols in cases in which such deficiencies occur. In a key study, Pollack and Matous (2019) conducted SNA for 3 months to examine the patterns of communication in a project team and inform team-building interventions. They focused on increasing personal communication comfort and bridging structural holes in the networks with their interventions, and observed a significant increase in personal and work-related communication frequency and network density. Pirzadeh et al. (2021) proposed a framework to investigate interdependencies and social interactions for design teams. They found that internal and external experts and the prevalence of closure and reciprocity in networks are helpful for effective design solutions, and can be monitored to inform possible intervention strategies. In the context of megaproject networks, Shi et al. (2022) highlighted the need for network controls and optimization strategies, which included the identification of impaired ties and nodes, dysfunctional networks, and implementation of network interventions.

Although the aforementioned studies set the stage for network interventions, the network intervention phenomenon remains understudied in the AEC domain. Additionally, most intervention studies focused on team building, and did not provide much insight into performance values and utilization of SNA. Repeatable intervention protocols across project network domains are needed to help contribute to the functioning of project teams by engaging networks and individuals as a part of larger teams (Matous et al. 2021). In AEC project teams, in which knowledge transfers are crucial, informal and formal networks (i.e., emergent communication networks versus organizational assignments) do not necessarily overlap or remain static (Franz et al. 2018), and collaboration priorities change (Garcia et al. 2021), the use of SNA shows great promise to optimize team dynamics across multiple organizations (Cross et al. 2014). To fill this gap, the researchers conducted a rigorous longitudinal study of AEC project networks considering the literature and developed a framework for AEC project teams that can be used to improve system functioning and as a foundation for the future

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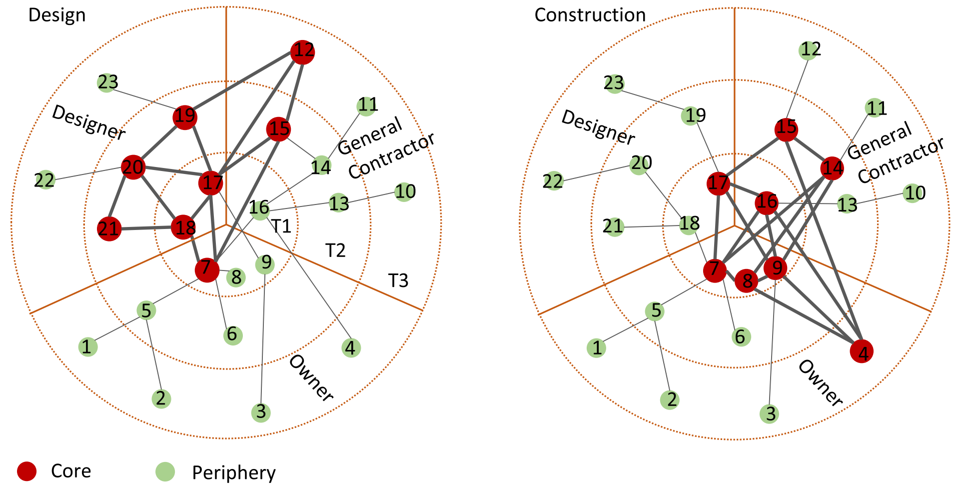


Fig. 2. Change of core and periphery members in collaboration networks from Interval 1 to Interval 2 depicted over the project's organizational structure. T1 = Tier 1; T2 = Tier 2; and T3 = Tier 3. Numbered nodes denote individuals.

development of automated social network interventions that can guide teams with just-in-time and intentional feedback.

Point of Departure

Considerations for AEC Teams

Two conditions unique to project teams exist, and they must be considered for network intervention adoptions in the AEC domain. First, projects go through cyclic phases, called progress loops, in which each phase becomes the input for the successor phase (Garcia et al. 2014; Marks et al. 2001). Progress loops correspond to project needs, and contribute to the evolution of network structures. A typical AEC project goes through schematic design, design development, construction documents, and construction episodes. Moreover, based on project progress such as cost, schedule, and/or scope changes, a project might have many more turning points, and these episodes might be broken down further into shorter time intervals. Depending on the nature of these progress loops (i.e., episodes and time intervals), the need for coordination or deep knowledge sharing might interchangeably become a priority for any project (e.g., planning and programming versus construction phases), leading to a variety of emergent collaboration network structures such as core–periphery and subgroups (Garcia et al. 2021).

Second, emergent collaboration networks in AEC project teams and individuals' positions in those networks might not align with their formal organizational structures (Zhao et al. 2021). For example, a general contractor's project manager, one of the assigned leads in an AEC project organization, is highly likely to be one of the core members in the collaboration network during the construction phase, whereas this might not be necessarily the case during design phases. Fig. 2 shows an example of changing core–periphery membership from design to construction nested in organizational structure [developed based on Garcia et al. (2020) and Mollaoglu-Korkmaz et al. (2014)].

Organizational structure in project teams follows contractual ties between parties, and most frequently includes three main roles (i.e., owner, general contractor, and designer) across three tiers. Tier 1 includes project leads, who hold decision-making authority in the day-to-day project operations; Tier 2 consists of team members in Tier 1 members' home organizations; and Tier 3 encompasses all other individuals associated with the project outside of the main organizations, such as subcontractors, vendors, consultants, and other stakeholders. An organizational network for a project team is based on contracts and assignments, and, for the most part, is static. However, any member of a project team can be in the core or periphery and can switch across different subgroups based on their communication behaviors at any given time in project delivery regardless of role, tier, and expertise area. Although different contractual arrangements impose different communication links and organizational structures at the beginning of the delivery process (Franz et al. 2018), as the project continues, new collaboration patterns emerge based on project needs (Garcia et al. 2021), team member characteristics (Chinowsky et al. 2018), and other factors such as trust or previous experience (Chinowsky et al. 2008).

Adoption of Network of Intervention Framework

Studying AEC projects, in the light of progress loops and misalignment between the organizational and collaboration networks as described previously, the researchers adopted Cross et al.'s (2006) network intervention framework. This section discusses the framework elements, namely central connectors, brokers, peripheral players, fragmentation points, and external connectivity.

Central connectors are the most central individuals in a network and have the highest degree centrality, which is calculated as the total number of connections linked to a node (Freeman 1978). As a simple example, if a project manager has connections with a designer, a mechanical engineer, and an electrical engineer, this individual has a degree centrality of three in this network. In AEC teams, Tier 1 members, who are assigned leads, are potential central connectors, and should be the primary focus of analysis. Additionally, core–periphery analysis helps to identify central individuals in a project team regardless of formal appointment (Borgatti and Everett 2000). Because they have the greatest number of direct connections, central connectors play critical roles in a network, and should be targeted to improve the diffusion of information and engagement. Interventions should also address their overload to improve network efficiency (Cross et al. 2006).

Brokers are knowledge leaders in a network who are strategically on the shortest path between unlinked team members and are ideal for disseminating knowledge (Cross et al. 2006). Betweenness centrality, which is calculated by counting the number of

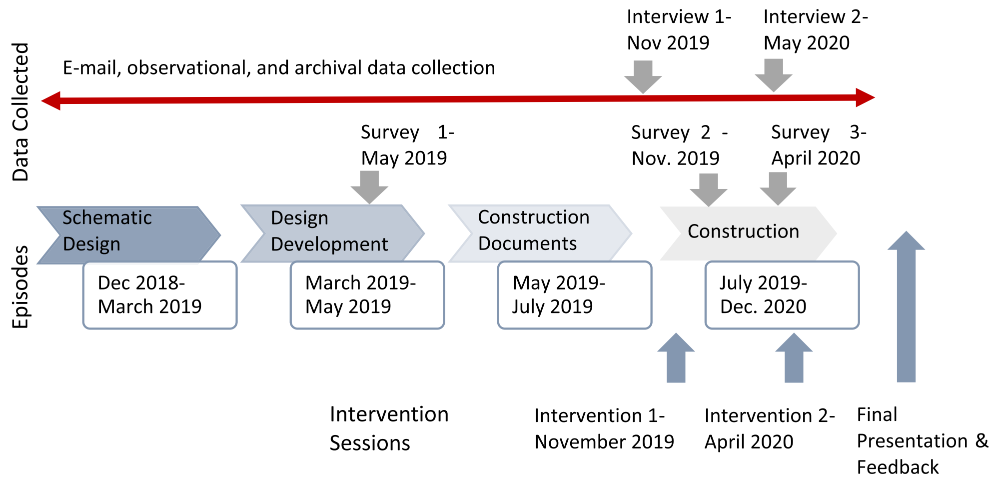


Fig. 3. Timeline of data collection and interventions in the case study.

geodesic paths that pass through a node (Freeman 1978), often is used in the literature to identify brokers in a network (Long et al. 2013; Marco et al. 2010). For example, a mechanical engineer working for the primary designer in an AEC project may communicate with an external mechanical design consultant and can function as a broker between the consultant and design leads from their organization.

Peripheral players are loosely connected members in a network with specific skills, resources, and expertise for a project, and are important because they provide novel information (Cross et al. 2006). Their integration can be critical for an AEC team in achieving collaboration (Zhao et al. 2021) and improved project performance (Garcia et al. 2020). For example, even a short involvement of a peripheral governmental representative in AEC project collaboration might bring the novel and necessary information relating to planning and programming on which the rest of the design team is dependent in order to complete their work.

Fragmentation points indicate the gaps in networks arising from a number of variables, including but not limited to expertise differences, hierarchy and power dynamics, and working in different locations (Cross et al. 2006). Such conditions are highly relevant to AEC project teams. For example, if a furniture vendor contracted to a general contractor is not copied in relevant emails by the designer, the project network relies on the general contractor as an information broker. If the general contractor does not connect the designer and furniture vendor in resolving relevant project issues, the vendor will be fragmented from the rest of the network, which inhibits problem-solving and successful execution. Although such structural holes can serve networks by eliminating redundant information and potential overload, having disconnected parties might inhibit the alternative options and innovation capacity in networks (Burt 2004).

External connectivity can enable learning from external stakeholders in networks (Cross et al. 2006). AEC project team members often are dispersed geographically and organizationally. Boundary spanners that cross technical, geographical, and cultural boundaries can facilitate effective knowledge transfers with external stakeholders, and help improve project performance (Duva et al. 2020; Marco et al. 2010; Ramalingam and Mahalingam 2011). For example, a mechanical engineer working for the general contractor can contact the designer's mechanical engineer to obtain information needed by crossing the organization's boundaries under deadline pressures to avoid schedule slippages instead of depending on project managers.

Methodology

The research team followed an exploratory approach to identify trends in team and project performance and corresponding network patterns. In this process, the research team (1) used qualitative and quantitative methods to examine performance and communication trends during project delivery and determined slowdowns, congestion points, and highlights in the networks; (2) studied the network trends via the lens of Cross et al.'s (2006) framework; and (3) developed the preliminary interventions and conducted interviews for vetting the developed intervention strategies before sharing them with the team members.

Data Collection

The research team collected data from an institutional major renovation and expansion project during its delivery for 2 years starting from schematic design until substantial completion (Fig. 3). The project had a budget of $22 million and was delivered via construction management at risk. The project team involved three main roles (i.e., owner, designer, and general contractor) and subteams including subcontractors, vendors, governmental institutions, and consultants. Throughout the project delivery, more than 1,000 team members were involved based on the project needs and schedule. The research team longitudinally collected archival (i.e., meeting minutes, project schedule, and documents shared on online document sharing platforms), survey, and communication data (i.e., email exchanges and observations of team meetings) and conducted interviews to develop the AEC network intervention framework. Using a diverse set of data from different sources helped the research team enable data triangulation and achieve research validity (Denzin 2007).

Archival data (i.e., meeting minutes, organization and team member rosters, project schedule, and documents shared on online document-sharing platforms) aided determination of the project's progress loops (Garcia et al. 2014; Marks et al. 2001) and creation of a timeline for data analyses. In this process, the research team first determined the start and end dates of the main project episodes as identified in project documents (i.e., schematic design, design development, construction documents, and construction), and then broke them down into monthly time intervals based on the cost growth, scope revisions, and major construction milestones as the key metrics. This process revealed 19 intervals, each spanning 4–8 weeks. Archival data also aided the calculation of project performance, as explained in the "Data Analysis" section. Two separate researchers independently coded the archival data and then compared findings to enable investigator triangulation and eliminate the risk of observer bias (Denzin 2007).

Using survey data, the researchers measured individual performances three times (i.e., in the design development, and construction phases) throughout the project delivery. In the surveys, team members who gave consent to participate in the research were given the names of the 10 people with whom they communicated the most frequently. Then, using a four-point Likert scale, participants were asked to evaluate their peers through questions relating to contribution to project execution, communication and coordination skills, adaption to changes, and innovation (e.g., completed tasks on time, and communicated effectively with the team members). Surveys included demographic questions such as experience in the AEC industry and with similar projects, areas of expertise, and education level to gain further insight into the project network.

To study team communication, first, the research team collected email exchange data consisting of email headers (i.e., subject, to/from, size, and date) through the project owner, designer, and general contractor. Email data helped eliminate self-reporting bias and provided insight into actual communication flows, because the project communication protocols required team members to send follow-up emails for documentation purposes if they used a different communication medium (Kadushin 2012; Quintane and Kleinbaum 2011). The research team created Excel macros to filter out the irrelevant data (i.e., based on email subject and by eliminating emails from senders who were not related to the project, such as promotional or personal emails). Second, two coders from the research team attended the weekly project team meetings, systematically recorded team interactions, and categorized communications in one of the following categories: (1) information given (e.g., "in the shower area, we have a steam room which will all be tile"); (2) information asked (e.g., "for how many mopeds is parking needed?); and (3) other (e.g., "let's go back to the schedule") (Frank and Zhao 2005). To maintain intercoder reliability, coders (1) compared and merged records after each project meeting and revised protocols as needed based on resolved conflicts, and (2) calculated the Spearman's rank correlation using their records for each team member observed. The average Spearman's rank correlation was about $r = 0.89$ ($p < 0.01$), indicating that coders' perceptions of how active each observed team member was in project meetings were similar. The data collected through observation also provided great insight into the communication and collaboration patterns of the team members, because the coders could observe all interactions (Wimmer and Dominick 2013).

Lastly, the researchers conducted five in-depth interviews (with a total of three project managers from the owner and general contractor, one design lead, and one user group representative from the owner) before the first intervention and two interviews (with a total of two project managers from the owner and general contractor) before the second intervention. Each interview took approximately 1 h, and was recorded and transcribed afterward. Compared with survey data, in-depth interviews provide accurate and detailed responses on sensitive issues (Wimmer and Dominick 2013). Additionally, the interviewees were the project managers or design leaders (i.e., all were Tier 1 members), who oversaw all major project activities for their organizations in the project from the project start. They were the main point of contact that everyone reports representing the rest of the population.

Data Analysis

Fig. 4 summarizes the data analysis steps. To evaluate team performance, the research team calculated survey scores for individuals based on peer evaluations (i.e., by taking the average of the scores given by the peers who were communicated with most frequently). We used archival data (e.g., meeting minutes and weekly look-ahead schedules) to calculate project performance. Members of our research team created a Gantt chart to track ongoing project activities and issues (e.g., finishing fire suppression piping above the ceiling, determining cable tray specifications, and so forth), the lead party responsible for those (i.e., owner, designer, general contractor), and the duration (i.e., number of weekdays) for their resolution. The researchers then calculated project performance during delivery for the whole project team and lead roles, using the ratio of resolved issues to ongoing issues per episode and time interval.

The researchers used email exchange data to determine the nodes and tie strengths in the project networks created across progress loops. The weight of the ties between nodes was determined based on the email communication frequency and assigned values of 3, 2, and 1 for daily, weekly, and monthly communication, respectively (Frank et al. 2015). Gephi version 0.9.5 software was used to visualize interactions based on the project's organizational structure and calculate network metrics such as centrality values of project team members. The archival data (i.e., organizational rosters, email extensions, project data, and meeting minutes) helped us determine the organizational assignments (i.e., role, tier, and expertise), and therefore the positions of individuals in the organizational networks. To evaluate the collaboration structure, UCINET version 6.773 software was used to determine the core–periphery structures (Borgatti and Everett 2000), and KliqueFinder version 0.15 software was used to determine subgroup structures, which maximized the concentration of close interactions within subgroups versus between subgroups (Frank 1995). Email exchange data and its representation of the overall project communication network were verified via (1) asking selected team members whether the 10 most frequently communicated people determined by the research team before the questionnaires were correct, and (2) presentations of sociograms in individual interviews prior to each intervention.

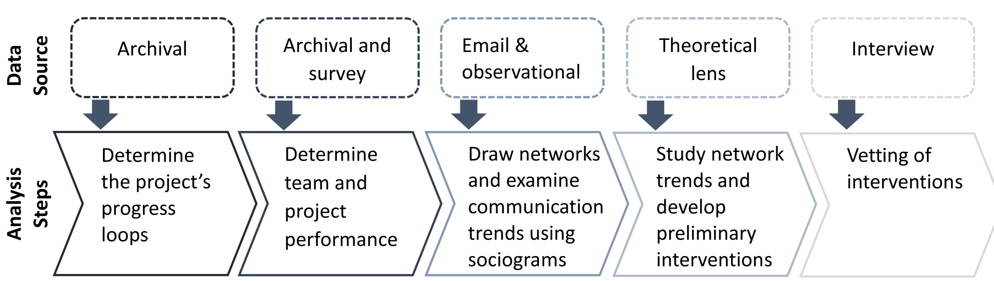


Fig. 4. Data analysis steps.

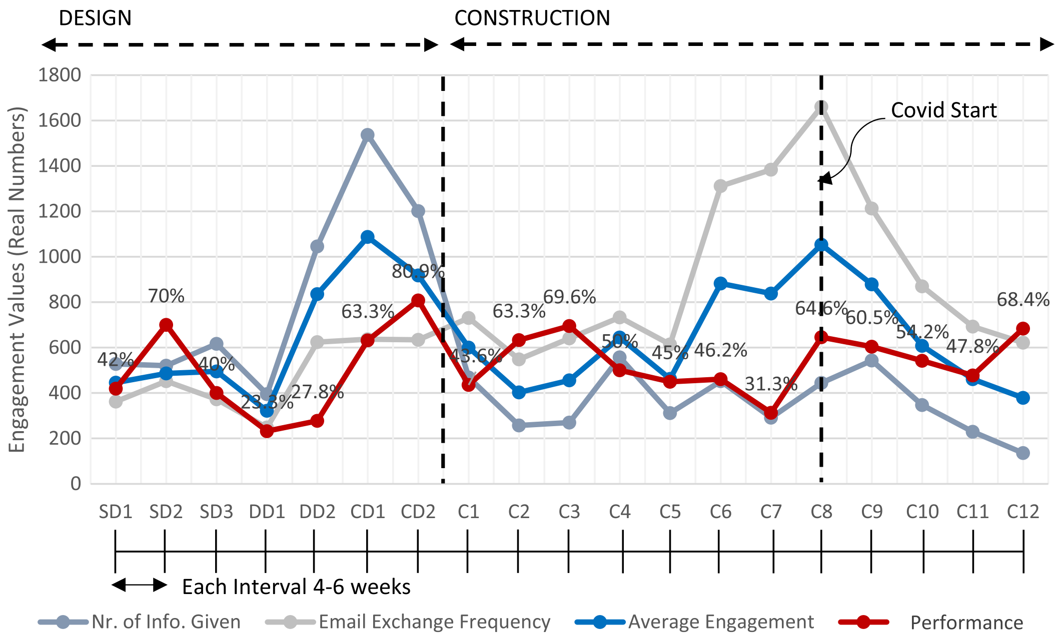


Fig. 5. Engagement versus project performance. Drastic increase in email exchange frequency in C8 corresponds to the COVID-19 shutdown and off-site working conditions. SD = schematic design; DD = design development; CD = construction documents; and C = construction.

Team meeting observational data also were incorporated in sociograms as node attributes and used for calculating individuals' engagement levels. We sized the nodes based on the information given by individuals in the face-to-face team meetings, as recorded by the research team. Thus, the larger a node in sociograms, the more engaged the individual was in team meetings. In addition, the total amount of information given was calculated for each interval as a measure of team engagement.

Using network visualizations and team and project performance trends over the course of project delivery, we determined possible misalignments, bottlenecks, and strengths and weaknesses in the networks, and developed intervention strategies accordingly using Cross et al.'s (2006) framework. Before sharing interventions with the project team members, we conducted vetting sessions through interviews with Tier 1 project team members to tailor the intervention strategies (Cross et al. 2014; Pinto Nunez et al. 2018).

The intervention sessions were conducted after the construction episode started (Fig. 3). Two of the authors guided the process and presented intervention strategies and implications to project team members. Eight to 10 individuals from upper management representing the owner, designer, and general contractor roles attended the sessions. Each session took 1–2 h. In accordance with the Institutional Review Board guidelines at Michigan State University, all data and findings were presented in an anonymous and aggregate form. When reporting findings, personal identifiers, such as organization, tier, or expertise area of the individuals, were altered purposefully to satisfy the anonymity of participants without compromising the data quality (Parry and Mauthner 2004). At the end of the intervention sessions, we conducted facilitated feedback from participants to collect further evidence for the use and impact of the interventions.

Results

Performance and Communication

Descriptive analysis of surveys indicated good team performance throughout the project delivery (i.e., the average performance of individuals for three time points was 3.5, 3.3, and 3.6 out of 4). Project performance (i.e., calculated as the ratio of issues resolved to the number of ongoing issues in any given progress loop) ranged between 23.3% and 80.9%, whereas the average performance was 67.4%, 62.3%, and 44.1% for the designer, owner, and general contractor, respectively, throughout the project delivery.

Fig. 5 shows the trends in project performance and team engagement (i.e., the total number of email exchange data and information given in the face-to-face meetings for an interval). Trends indicated a link between the average team engagement and the issue resolution rate. For example, project performance and engagement both decreased in Design Development 1 (DD1), whereas they both peaked with a 2-week lag between the Construction Documents 1 (CD1) and Construction Documents 2 (CD2) intervals. The only exception to this alignment of performance and engagement trends was early in the construction phase (C1 and C4), and the inconsistency might be attributed to changing project needs, changes in the communication lead (designer versus general contractor), and dynamics due to the transition from the design to the construction phase. With the involvement of new individuals in the construction phase, we observed that the core–periphery structure dissolved and evolved to a subgroup structure (Frank 1995).

Based on the highs and lows of performance and communication trends during project delivery (in terms of the issue resolution rate and SNA metrics) and potential links among them, we focused on differences in the communication networks (using sociograms in given intervals) for the owner, designer, and general contractor roles, and interpreted the network findings.

Network Observations

Following Cross et al.'s (2006) framework, we observed the following network characteristics.

Central Connectors

Tier 1 members emerged as the central connectors with the highest degree centrality values based on email exchange data (e.g., for the schematic design, the average degree for the whole team was 8.45,

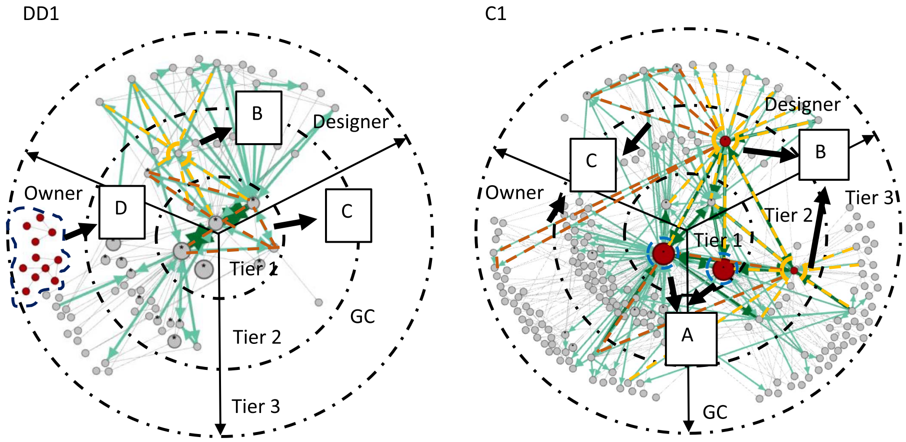


Fig. 6. Sociograms depicting network observations. A = overload on central connectors; B = brokers; C = triadic closures; D = network fragmentation due to lack of a broker; DD1 = design development 1; C1 = construction 1 interval; and GC = general contractor.

whereas it was 85.57 for the Tier 1 members, with a range of 34–126).

Based on the sociograms, we observed two assigned leads in the designer's Tier 1 throughout the project delivery. Both leads had more than 15 years of industry experience and had worked on more than 10 similar projects, according to the surveys. They actively functioned in project communication in the face-to-face meetings and were involved in the network core throughout the project delivery based on UCINET results. The owner started with two leads in Tier 1, however, one lead left the project (i.e., staff turnover) after the Construction Documents episode. Both leads were highly experienced (i.e., they had more than 15 years of experience and had worked on more than 10 similar projects), were active in face-to-face meetings, and were in the network core. Although the general contractor had two assigned leads in Tier 1, the lead with most experience (i.e., more than 15 years of industry experience) did not attend the face-to-face meetings after Design Development, and left the network core based on communication frequency. The lead with relatively less industry experience (i.e., 5–10 years) actively functioned in the communication network and remained in the network core.

Accordingly, the active and experienced two-lead structure in Tier 1 emerged as a potential issue that might have helped the designer achieve better performance, compared with the general contractor during project delivery. Having only one person in owner Tier 1 did not significantly impact the performance of the owner (i.e., 62.3%), because the owner never led the project team communication. Having one active lead in Tier 1 might have caused unbalanced workloads among the general contractor and owner based on their connections and node size (Fig. 6, A). The overload on Tier 1 of the owner due to personnel and phase transition is evident in Fig. 6 between the DD1 and C1 intervals.

Brokers

We observed that two Tier 2 team members, one under the designer and the other under the general contractor, emerged as information brokers (in the Design development 1 and Construction 1 intervals, respectively) with high centrality (e.g., in the Construction 1 interval, in a network of 200 people, the two brokers had the third and sixth highest betweenness centrality and the fifth and third highest degree centrality, respectively). They were in the network core after they were involved in the project team. They were highly active in diffusing information upwards and downwards in the project organization (Fig. 6, B).

Before the involvement of these brokers, strong triadic closures, which facilitate knowledge transfers, mostly were limited to Tier 1. After the involvement of the brokers, triadic closures expanded to Tier 2, and to Tier 3 members (Fig. 6, C). Moreover, the broker of the designer had more experience in the industry than the general contractor's broker (i.e., more than 15 years and 1 year, respectively), and was involved in the project as early as the Design development 1 interval (DD1). Early involvement and having a transition period until the designer's broker actively started bridging different parties of the network might have contributed to better team performance for the designer.

In the analyses for the case study project, the lack of a Tier 2 broker in the owner group placed the entire communication load on the project lead and created a hierarchical communication structure. This situation did not impact the performance of the owner, because the owner did not spearhead the project communication coordination (these roles were fulfilled by the designer during the design phase and by the general contractor during the construction phase). However, such conditions may result in negative consequences, and can affect the project network functioning adversely if the team leader is unable to serve as the hub of information.

Peripheral Members

Analyses demonstrated that the lack of peripheral members impaired the pace of issue resolution. For example, during the Design Development 1 (DD1) interval, in which the team performance was the lowest, engagement of the peripheral experts in the project network and face-to-face team meetings was the lowest. Additionally, the composition of the core was not diverse; only Tier 1 members were involved, and there was no involvement of peripheral members in active collaboration.

Fragmentation Points

During project delivery, experts, especially from Tier 3, entered and exited the project network on an as-needed basis depending on the phase of the project, and it was in this phase that the most fragmentation occurred. We observed that due to expertise differences, a group of individuals formed a clique in the network, in which they were highly connected to each other but were disconnected from the rest of the network. Network fragmentation occurred mostly under the owner (Fig. 6, D), due to a lack of ties connecting Tier 3 to Tiers 2 and 1.

External Connectivity

Like peripheral members, external connectivity and boundary-spanning ties bring novel information and enhance innovation

(Marco et al. 2010). The leads and broker under the designer role were more involved in interactions within and across their roles and tiers than were those under the general contractor role. e.g., during the Construction 1 interval (C1) (Fig. 6), which might have helped achieve better performance.

Intervention Framework and Feedback

Fig. 7 summarizes the intervention framework adopted from Cross et al. (2006) and strategies developed for the AEC teams based on the observations presented previously.

Teams of Two as Central Connectors

In Tier 1 of each role, it is ideal to work in teams of two, in which one person is the Technical Lead making decisions, and the other person is the Communication Lead facilitating key information exchange among relevant areas of expertise to support the technical lead closely. Both individuals should be experienced in project-specific technical domains. Participating roles should ensure continued engagement of technical and communication leads of two in Tier 1 throughout project delivery, but especially during the phases, in which they spearhead the team communication. Having a team of two eliminates communication overload and increases network resiliency during personnel and phase transitions. When there is only one person in Tier 1, communication overload might occur. It is highly beneficial if at least one of the leads under a given role has prior experience with leads under other roles, because it was observed that prior working experience can reinforce trust and help improve project team efficiency. Interview results supported our finding:

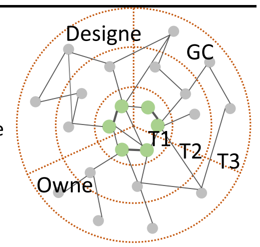
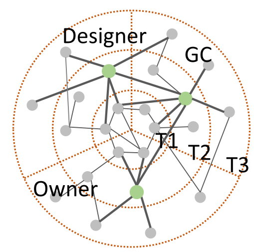
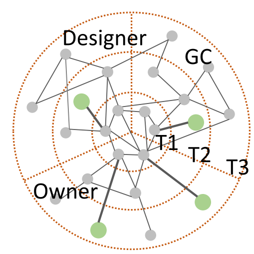
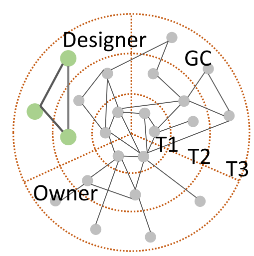
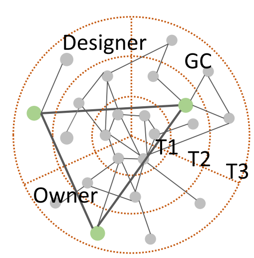
Network Element	Importance	Possible Threats	Strategy for AEC Teams	Network Visualization
1. Teams of Two as Central Connectors	Critical with the most direct connections; thus, should be addressed to improve engagement	Likely to experience communication overload if not appropriately supported in the networks	• "Communication and technical leads" in tier 1 as teams of two per role • Qualification-based selection-prior experience • Continuing engagement of the leads. • Balanced leads for network resiliency.	
2. Communication Support as Brokers	Informal informational leaders who are on the shortest path between others and are ideal to diffuse information	Likely to experience structural holes and delays in getting necessary information if missing a broker	• "Communication support" in tier 2 connecting tiers, roles, and experts • Empowering a broker in designer starting with design phase and in GC starting with construction	
3. Peripheral Players	Individuals with under-used and novel skills, expertise, and knowledge	Likely to experience information redundancy if peripheral members are not involved	• Expertise integration from the "peripheral members" within or outside of the organization • Inviting them to face-to-face meetings for planned times based on the needs	
4. Targeted Involvement for Fragmentation Points	Fragmentation points are gaps in the networks due to expertise differences, hierarchy, or location	Likely to have disruptions in knowledge transfers if not addressed	• Targeted involvement of experts by activating the brokers (i.e., communication support) in tier 2 to promote necessary expertise	
5. Boundary Spanning for External Connectivity	Connecting external stakeholders, who are technically, geographically, or culturally dispersed	Likely to experience information redundancy, lack of expertise diversity, and innovative solutions	• Active engagement of the team members from different roles/tiers and expertise and enabling boundary spanning	

Fig. 7. Social network intervention framework for AEC project teams.

> I think this is a high-functioning team because we have worked on projects before. There are a few [new team members]. We can effectively communicate and there is an added level of trust going through the other projects.

Additionally, personnel changes are common in project teams. Before personnel transitions during project delivery, especially for the high influence roles, having an overlap period between the people that transition in and out of the project team to transfer the necessary know-how and mitigate negative impacts is helpful. Moreover, phase transitions should be taken into account as well. Although the project moves into a new phase (e.g., from design development to the construction documents episode), the communication network does not necessarily follow the same progress. During transitions, team members might become overloaded taking on new roles in addition to continuing roles. One interviewee reported on the personnel turnover in owner Tier 1 accordingly

> I am really seeing a difference in organization and leadership with [this individual] gone. It has been a learning curve for me changing in the middle of the project.

Communication Support as Brokers

Organizational assignment of Communication support in Tier 2 as a broker to assist Communication lead in Tier 1 is recommended, especially in the designer and general contractor roles, who spearhead the communication coordination of projects (i.e., design and construction phases, respectively). Such brokers help bring timely input and prevent communication overload in Tier 1. Without communication support, structural holes and network fragmentations might occur (Fig. 6). Involvement of communication supports also strengthens the triadic closures (i.e., complete ties among three actors) across tiers and roles. Regarding communication support, one interviewee reported

> Coordination falls on [communication support]. [This person] communicates both up and down [Tier 1 and 3], making sure that we are either involved in meetings if necessary or filters info from/to consultants.

Peripheral Players

Central connectors (project leads in Tier 1) and brokers (communication support) should engage effectively with peripheral players to leverage the knowledge flows. Instead of relying solely on email communication and copying peripheral members on email threads, project leads should consider inviting them to face-to-face meetings for targeted discussions for a limited and planned time to protect them from communication overload. One of the interviewees reported about having peripheral members in the face-to-face meetings as follows:

> I think it is trying to optimize and recognize that they have a busy schedule, and you don't want to sit through 3 hours design meeting. And I can get some information through them, and they don't need to sit in the meetings. I can get the little components.

Targeted Involvement

Targeted involvement of related expertise areas across should be ensured to eliminate fragmentation points in the project network and integrate necessary expertise. It is especially important that communication supports in Tier 2 should find the holes in the communication network and immediately contact relevant experts before tasks fall behind schedule, and they should be intentional in activating subteams in Tiers 2 and 3 within their role to prepare for upcoming issues.

Boundary Spanning for External Connectivity

Team members should remain adaptive in their communication exchanges with others regardless of their tiers and role. To ensure external connectivity, project leads should encourage an environment of collaboration and trust to promote boundary-spanning knowledge transfers. One of the interviewees reported on boundary-spanning ties as follows:

> I don't have to have all communication and to be in the middle of it. I can delegate some of that. When I have those conversations with the mechanical engineers within our organization, they can reach out to the designer and communicate together and come back with a result, and then I can give directions to the general contractor.

Similarly, team members should not depend on Tier 1 members to facilitate and/or initiate information exchanges when relevant project issues are present and should keep managers in the loop. One lead from the general contractor reported on boundary-spanning ties as follows:

> Whatever you cross the line [e.g., from Tier 2 to Tier 3], the primary folks are aware of those conversations. We asked to be copied in these conversations. If we are not a part of the conversation, we asked to be summarized and published.

Postintervention feedback also proved that the observations and findings of the study reflected the project delivery processes and communication strings of the team. The team members commented that the sociograms and intervention strategies gave insight into how team members communicated during the project delivery and how communication should be facilitated in future projects. They also highlighted that the findings should be shared with senior leadership in the organizations to create awareness of organizational assignments, team member selections based on qualifications, skill development, and project management.

Discussions

Consisting of a wide range of experts, organizations, and stakeholders, AEC project teams are complex and prone to impairment. Enabling successful knowledge transfers and collaboration among team members is of utmost importance to successfully deliver a project. This study analyzed an AEC project network systematically and thoroughly to shed light on how team collaboration might be improved through informed network interventions. Although project characteristics such as complexity, delivery method [e.g., design–build and construction management (CM) at risk], contractual relations among parties, and timing of general contractor's involvement in the process highly impact network dynamics and team collaborations, the literature shows support for the applicability of study findings to a larger context of AEC projects (Mollaoglu-Korkmaz et al. 2013).

First, AEC project teams might benefit from having a team of two for each primary role (i.e., owner, designer, and general contractor) consisting of a technical lead making decisions and a communication lead facilitating key information exchange among relevant experts. Clear communication of client requirements and diffusion of technical knowledge is necessary for successful project execution (Cross et al. 2008). Therefore, owners should consider involving team leaders representing primary project roles early in project delivery (Franz et al. 2017), especially in high-profile

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projects, in which project needs and expectations are greater. Having two leaders in primary roles can help improve team resilience during personnel and phase transitions and can avoid bottlenecks (Cross et al. 2006). The findings also indicate that trust is an important prerequisite for effective knowledge transfers, and therefore for project performance (Cheung et al. 2013; Chinowsky et al. 2008). Prior working experience was observed to reinforce trust and effective knowledge transfers between team members, because teams with prior experience can resolve conflicts and adapt to contingencies more easily, instead of depending on contractual relationships (Girmscheid and Brockmann 2010; Lee and Chong 2021). Therefore, selection of individuals with previous work experience with each other, especially in key roles such as technical and communication leads and support, can be highly beneficial.

Second, it is recommended that there should be communication support in Tier 2 as a broker to assist the communication lead in Tier 1. Therefore, responsible parties should ensure timely involvement of communication support and should empower them, because they help disseminate project information upward and downward in tiers and across different roles (Liu et al. 2022). Involvement of communication supports also strengthens the triadic closures (i.e., complete ties among three actors) across tiers and roles. Although triads might seem redundant, they might strengthen trust (Henry and Vollan 2014), facilitate cooperative behaviors, and improve resiliency for staff turnovers (Franz et al. 2018).

Third, the results are in agreement with the literature and suggest that project leads and brokers should engage effectively with peripheral members by inviting them to face-to-face meetings (Cross et al. 2006) for targeted discussions for a limited and planned time to protect them from communication overload, which will improve their problem-solving (Zhao et al. 2021) and their sensitivity toward project priorities (Cross et al. 2008). Similarly, by joining the fragmentation points to the rest of the network with the involvement of the communication lead and support, the transmission of new ideas and knowledge transfers can be promoted (Kadushin 2012).

Fourth, team members should remain adaptive in their communication exchanges with others regardless of their tiers and role by crossing the boundaries of role, tier, and expertise. In agreement with the literature, having boundary spanners facilitated effective knowledge transfers with external stakeholders and helped improve project performance (Duva et al. 2020; Marco et al. 2010; Ramalingam and Mahalingam 2011). The management team should empower relevant experts to get engaged by spanning the boundaries of their role, tier, or expertise by keeping the management in the loop.

Lastly, project teams may have different network structures which evolve dynamically (such as going from core–periphery to subnetworks and vice versa based on network needs facilitating coordination and deep knowledge sharing) (Garcia et al. 2021). Core–periphery structures enable better team coordination, and subgroup structures promote deep knowledge transfers (Borgatti and Everett 2000; Parraguez et al. 2015). Our findings show that an overlay of networks on organizational structures (e.g., Fig. 2) provides a deeper understanding of team dynamics in AEC project teams and offers expanded applicability of the findings across different projects.

Conclusion

Network interventions can help improve project efficiency and performance by enabling necessary practices and desired behaviors, and generating social influence (Valente 2012), but there is a lack of robust intervention protocols that can be repeated for AEC project networks (Matous et al. 2021). This study contributes to the body of knowledge by using social network analysis to provide (1) an intervention framework for AEC teams to improve the efficiency and performance of project communication networks, and (2) guidance to AEC industry practitioners in selecting and assigning experts in key roles and positions in project networks to efficiently manage team communications during delivery.

The results provide the intervention implications of organizational assignments, communication and coordination practices, and skill development that project executives and personnel can use for timely improvements in the AEC project delivery. First, project organizations should consider having technical and communication leads in Tier 1 of each role (i.e., owner, designer, and general contractor) to balance the workload and ensure the necessary knowledge transfers. Second, communication support in Tier 2 as an information broker can be highly essential in designer and general contractor roles to assist project communication coordination. Third, peripheral members and fragmentation points should be joined to the rest of the network to promote the diffusion of novel information by using communication support and by inviting them to face-to-face meetings in a limited capacity. Fourth, the management team should ensure that relevant experts are engaged by spanning the boundaries of their role, tier, or expertise by keeping management in the loop.

Limitations exist in this study that should be considered and addressed in future research. First, this research used Cross et al.'s (2006) framework to develop strategies for AEC teams using data from a single, medium-size case study delivered using construction management at risk, which might limit the generalizability of the findings. In addition, although the literature and our participant verifications provide validity to our methods, we acknowledge that each project is unique, and parameters such as contract types, communication protocols, and characteristics of team members might impact the findings and team performance.

Therefore, future research should use data from larger or smaller projects in different settings to test and validate the applicability of the intervention strategies. Specifically, future research can explore personality characteristics of team members that enhance system functioning. Future research also can focus on automating the development of social network–based evaluation of project teams by using technology to provide real-time feedback during project delivery, continuously improve participants skills, and enable individual learning. This study provides a foundation for future work including but not limited to application in other industries for project team interventions across disciplines and organizations.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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