Integrative Collaboration in Fragmented Project Organizations: Network Perspective

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Abstract: Architecture, engineering, and construction (AEC) project teams have a segmented organizational structure with subgroups, for example, designer, contractor, and owner. AEC projects are challenging to collaborate because they require those in different subgroups to address uniquely defined technical and functional contexts. The AEC industry often seeks integrated collaboration through organizational integration because the literature assumes that organizational structure determines collaboration structure. This study uses a network perspective to identify the inconsistency between the organization and collaboration networks through the data of email records from a $20 million AEC project with a typical fragmented organization. The analytical focus is on two network configurations: (1) a community structure through which subgroups are defined to attend to specific aspects of the project and then coordinated through ties between members of different teams; and (2) a core-periphery structure in which a relatively small number of members interact frequently in the core and then coordinate as each member of the core interacts with specific members of the periphery. Results provide evidence of integrated collaboration in fragmented project organization, indicating organizational integration is not a must to achieve integrative collaboration. The findings suggest implications to facilitate integrative collaboration: (1) efforts should focus on collaboration behaviors, (2) subgroups should adopt a dual-lead pattern, (3) subgroups should encourage non-high-profile members to function as cores, and (4) subgroups should ensure information sharing and prevent information overload. **DOI:** 10.1061/(ASCE)CO.1943-7862.0002149.

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Introduction

Architecture, engineering, and construction (AEC) projects are complex due to their temporary and dynamic nature with varying individuals, entities, and expertise areas (Korkmaz and Singh 2012). AEC project organizations are typically fragmented because they involve a large set of subgroups who play different roles such as architects, engineers, constructors, and consultants (Garcia et al. 2020; Sacks et al. 2018; Zhao et al. 2016). The fragmented nature imposes a significant challenge on AEC project members to collaborate integratively and effectively.

Researchers and practitioners advocate integrative project delivery methods (e.g., integrated project delivery and design-build) to tackle the fragmentation problem. In practice, technical and managerial measures are used to create an integrative project organization and then member connectivity (Ahmad et al. 2019; Elghaish and Abrishami 2021). The measures generate a project organization network (formal), and member interactions in project collaboration generate a collaboration network (informal). However, it is an open question whether the formal organization network is aligned with the informal collaboration network. A better understanding of this problem will inform what types of network configurations can emerge from interactions among project members. This understanding is especially important for AEC project management in two aspects. First, the creation and maintenance of organization network require resources, time, and investment. For example, data sharing among stakeholders needs infrastructure and human resources. Second, the cost to create and maintain the organization network can be high across multiple stakeholders.

The objective of this study is to explore whether the configuration of the collaboration network aligns with that of the organization network. We focus on network configurations whose characteristics influence collaboration behaviors (Ouchi 1977). We particularly look at two network configurations: (1) the community structure through which subgroups are defined to attend to specific aspects of the project and then are coordinated through ties between members of different teams, and (2) the core-periphery structure in which a relatively small number of members interact frequently in the core and then coordinate as each member of the core interacts with specific members of the periphery (Borgatti and Everett 2000).

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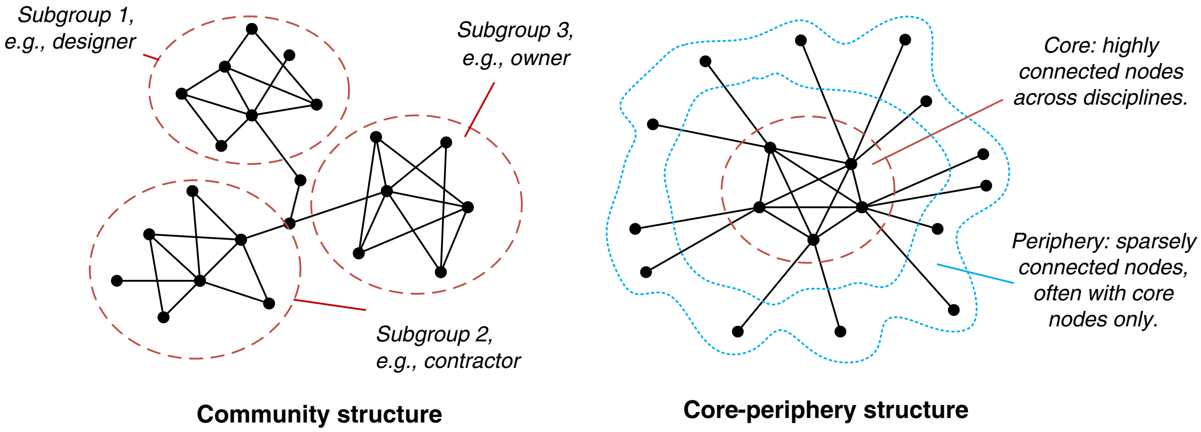

Fig. 1. Exhibition of community network and core-periphery network configurations.

We analyze an AEC project that has a common community organization network (i.e., each subgroup has independent contract, personnel, and operations) and examine whether its collaboration network can be core-periphery. We also describe the attributes of project members who occupy different positions in that configuration. Overall, the outcomes help AEC project management to evaluate administrative investment on team collaboration because stakeholders, such as architects, engineers, consultants, contractors, owners, subcontractors, and suppliers, are likely to complete tasks independently and collaborate internally (Boddy et al. 2000; Sacks et al. 2018).

Literature Review

Network Theory

Network theory is widely used to visualize member connections in project organizations (Moody et al. 2005). A network includes a set of nodes and ties between them. In AEC project studies, network nodes typically represent project members and ties represent interactions or relations among the members. Network configurations affect individual behaviors and team performance (Frank et al. 2015; Friedman and Miles 2002). Also, networks change when project members respond to potentially complex demands of production (Frank et al. 2018a).

Networks influence organizations through functions such as selection and influence (Frank et al. 2018a; Frank and Fahrbach 1999). The selection function indicates how a project member seeks out other members to access information. Selection is relevant to how far away an AEC member is from a network (i.e., network distance). Many factors influence the selection process. For example, members prefer to select ones who hold similar beliefs (homophily). Another factor is organizational identification, which refers to mutual notice and recognition. If organizational identification is high, members are likely to respond to organizational norms and select ones with whom they have an affinity (i.e., people matter). On the contrary, if organizational identification is low, members are likely to select ones who have new information to share (i.e., information matters).

The influence function indicates changes in member's beliefs or behaviors as a result of interactions with others. For example, a project manager decides to use building information modeling (BIM) because they receive critical information from BIM experts. Overall, networks affect employees' attitudes and behaviors as well as the collective culture, climate, and performance. The selection-influence models can elucidate such complex organizational behaviors, e.g., complex interactions, behavior patterns, innovation diffusion, and practical adoption. That is, networks influence individual members and their behaviors in organizations through people they interact with (people effect) or new information they receive (information effect).

Network Configurations

Project members address complex tasks of production through a community network configuration (Fig. 1), where each subgroup is tasked with a specific function. For example, a subgroup may be responsible for HVAC systems and another for concrete. Dense or intense ties within each subgroup allow members to share knowledge (Hansen 1999), and frequent interactions allow them to coordinate their actions (Du et al. 2020; Nonaka 1994) to complete complex tasks. Actions are coordinated between subgroups through bridging ties that involve less frequent and less intense interactions between members of different subgroups (Simon 1962).

The capacity of the network then resides in the bridging ties. Are the bridging ties strong enough to sustain coordination between the different subgroups? Do the project team members attempting to bridge have the capacity in terms of time and knowledge to engage in interactions with members of other subgroups as well as their own? If the answers are no, then team members may generate and occupy different types of roles to share knowledge and coordinate the action of the whole team. In particular, a subset of actors may take on the primary goal of coordinating and sharing knowledge among members of different project subgroups. That is, a subset of members may define a new type of subgroup in which they interact extensively with one another, relieving the others of the need to directly coordinate or share knowledge. This unique subgroup then comes to occupy the core of the network (Fig. 1).

That is, the core is a group of project members who are central to the project team, and they frequently interact with each other (Borgatti and Everett 2000). The periphery is then the set of project members who have a small number of interactions, and typically those interactions are with only the core members (Boyd et al. 2006; Rombach et al. 2017). Because of the unique and intense role of the core, core-periphery configurations cannot be easily reduced to subgroups (Borgatti and Everett 2000).

Collaboration Network in AEC Projects

The core-periphery configuration facilitates rapid flows in networks because once core members adopt an innovation or obtain new information, they convey it directly to others throughout the network (Berardo and Scholz 2010; Frank et al. 2018b; Newman 2005). Not surprisingly, the core-periphery configuration has been empirically identified in several contexts such as earth science, traffic planning, economic development, the world trade system, and academic interactions (Goldgeier and McFaul 1992; Kostoska et al. 2020; Snyder and Kick 1979).

Project management fosters integrative project collaboration through fostering integrative project organization, using technical and managerial approaches. For example, virtual design and construction (VDC) represents a technical approach (Du et al. 2020; Redmond et al. 2012; Singh et al. 2011; Zhao et al. 2015); and integrated project delivery (IPD) represents a managerial approach (Bilec and Ries 2007; Swarup et al. 2011; Verheij and Augenbroe 2006). VDC takes advantage of information and communication technology to enhance integrative organization. IPD relies on contractual provisions to bound integrative organization. These approaches are top-down, administrative, and contractual measures (Ahmad et al. 2019; Elghaish and Abrishami 2021) and aim to create member connectivity The measures reshape team assembly and organizational hierarchy (Roger et al. 2005) and generate an organization network (formal) that indicates the nature of relationships in project execution. Team assembly decides the nodes of the organization network (i.e., who are members) and organizational hierarchy decides the ties of the organization network (i.e., who reports to whom). Configurations of the organization network should serve project goals and be consistent with team needs and constraints. Hopefully, project members interact with each other and share knowledge, where a collaboration network (informal) emerges (Frank et al. 2018a). Configurations of collaboration network affect productivity, communication, and engagement (Freeman et al. 2007; Zhao et al. 2021).

Overall, our research question turns to be whether the configuration of the collaboration network aligns with that of the organization network.

Data and Methods

Case Project Background

The case project is a major building system renovation project, located in the US Midwest. The number of project members varied from approximately 120–210 across different project delivery phases. The project started in September 2018 and was expected to complete in December 2020. The project consists of a 3,252 m^2 (35,000 sq ft) addition and infrastructure improvements to address increasing energy demand, with an overall project budget of $20 million. Like most AEC projects, this case project has segmented project organization with three formal subgroups: the designer, contractor, and owner/consultant. The three subgroups worked independently, led by three independent entities, i.e., a design company, a general contractor company, and a facility management department from the owner. The project represents a complex organization and causes coordination challenges to project members.

We collected project emails to identify the network configuration of collaboration among project members. Many existing studies have used email data to model team collaboration and examine complex AEC networks (Albino et al. 2002; Dogan et al. 2015; Durugbo et al. 2011). Email data are representative of team collaboration interactions and particularly appropriate in this study for three reasons:

- Emails remain a primary communication tool in AEC project management.
- Extensive use of emails in project management facilitates efficient information exchange, documentation, and reliable decision making (Stanton 2004). Emails allow geographically dispersed members to collaborate remotely and share accountability (Gimenez 2006).
- Emails are a reliable data source about interactions. The project manager, construction manager, and chief architect of this AEC project in their interviews confirmed that the networks we identified from email data represent their collaboration patterns.

Procedure

Email data were collected during the project's schematic design phase from 2018 to 2019. We reached out to the designer subgroup and requested their daily emails because they played a major role in this phase. The designer subgroup agreed to extract all project-related emails from their central email server and provide them to us. To ensure research reliability, we also collected email data from the contractor subgroup. Per our request, the contractor subgroup granted access to the email exchange system and we directly exported email data from the system. We incrementally collected the email data every other week until the end of the schematic design phase. Also, we periodically produced networks and confirmed them with key project members (e.g., project manager) and sought their feedback from follow-up interviews in their project meetings.

In-person interviews verified that communication patterns and ties illustrated in the networks reflect project-specific team interactions. Although project members from the same subgroup may use different media for communication (e.g., face-to-face or phone calls), they reported that they send follow-up emails for documentation purpose. Based on communication strings structured by contract, decisions made by other communication media should be reported through confirmation emails. Because this study involved human subjects, we strictly followed the data collection procedure reviewed and approved by the Institutional Review Board (IRB) at Michigan State University. We began to collect email data and conduct interviews only after obtaining the IRB approval letter.

Data Collection

The email data included headers only and excluded the content due to confidentiality issues based on the IRB compliance. The headers provided five pieces of useful information: (1) From, i.e., the email sender, (2) To, i.e., the direct email receipt, (3) CC/BCC, i.e., the carbon copied recipients, (4) Time, i.e., when the emails occurred, and (5) Subject, i.e., the email title, often briefing the content.

We obtained the project members' expertise area and their connections from the contact address-book system. We confirmed with the project manager when we were uncertain about the expertise area of project members. To eliminate unrelated and duplicated emails, we conducted quality control to align the email data from the designer and contractor sides. The final data included 150 project members and 897 emails occurring from December 2018 to March 2019.

Table 1 summarizes the 150 project members in project collaboration. We assigned each member a unique node ID. We then coded the project members by the organizational subgroup (i.e., designer, contractor, and owner) and expertise area (e.g., architectural design, electrical engineering, or construction). Some listed node IDs were beyond the range of 1–150, for example, 191, 294, or 329. This is because, although we found more than 300 email addresses (nodes) from the data, some email addresses were not related to the project and thus excluded from the data analysis, e.g., mail-list addresses and news subscription addresses. Project members with the expertise area of architectural design occupy the largest portion, accounting for 16% of total members.

Table 1. List of project members in collaborative network

Subgroup	Code	Expertise	Nodes	Count	Percentage (%)
Designer	Arch	Architectural design	97, 128, 191, 219, 286, 288, 294, 301, 303, 309, 314, 324, 328, 329, 333, 343, 353, 360, 366, 369, 372, 381, 382, 387	24	16.0
	Civil	Civil engineering	258, 340, 365	3	2.0
	Const	Construction	290, 293, 297, 302, 374	5	3.3
	Elect	Electrical	77	1	0.7
	Lands	Landscape design	158	1	0.7
	Manag	Management	56	1	0.7
	Mecha	Mechanical	66, 135, 304, 337	4	2.7
	OPlPr	Organizational planning and programming	308, 357, 361	3	2.0
	Plann	Project planning	284, 306, 307, 334, 339, 368, 376, 379	8	5.3
	Speci	Specialty design	287, 291, 296, 298, 344, 371, 350	7	4.7
	VeOth	Vendor or others	319	1	0.7
Contractor	Civil	Civil engineering	352	1	0.7
	Const	Construction	11, 289, 292, 330, 338, 347, 354, 356, 358, 370, 373, 388	12	8.0
	Manag	Management	195, 235, 327	3	2.0
	Mecha	Mechanical	345	1	0.7
	OPlPr	Organizational planning and programming	385, 386	2	1.3
	Plann	Project planning	146, 299, 311, 313, 315, 349, 362, 380	8	5.3
	VeOth	Vendor or others	320, 336, 383	3	2.0
Owner	Arch	Architectural design	1, 220	2	1.3
	Civil	Civil engineering	6, 88, 237, 260	4	2.7
	Const	Construction	145, 147, 285	3	2.0
	Elect	Electrical	26, 217, 251	3	2.0
	Inter	Interior design	86, 275	2	1.3
	IT/AV	IT, audio, and video	40, 134, 148, 185	4	2.7
	Lands	Landscape design	150, 271	2	1.3
	Manag	Management	266	1	0.7
	Mecha	Mechanical	10, 58, 87, 93, 104, 136, 160, 236, 272	9	6.0
	MEPco	MEP construction	5, 45, 79, 186, 242	5	3.3
	OPlPr	Organizational planning and programming	37, 62, 74, 167, 193, 218, 342, 351, 391, 407	10	6.7
	Needs	Project needs and program	13, 21, 41, 46, 60, 106, 214, 269, 348	9	6.0
	Plann	Project planning	159, 169, 179, 201, 273, 278, 398	7	4.7
	VeOth	Vendor or others	25	1	0.7

Note: IT = information technology; and MEP = mechanical, electrical, and plumping.

Analytical Approach

We particularly examined the project collaboration network that included information of senders (i.e., From) and all recipients (i.e., To and CC). In the social network analysis (SNA), email addresses (i.e., project member) indicate nodes, and email records indicate ties. For example, if X sends an email to Y and copies it to Z, then three nodes (X, Y, and Z) are coded and two ties (X to Y and X to Z) are recorded in the network. Although it is obviously segmented, we mapped out the project organization network of the three independent companies based on the hierarchy and expertise, i.e., the supervisor and subordinates (Hall 2018).

We performed the following three types of analyses on the collaboration network: (1) network visualization to describe the social network such as nodes and ties, (2) network descriptive analysis to calculate network properties including density, degree centralization, betweenness centralization, closeness centralization, and eigenvector centralization, and (3) structure tests to verify if the network satisfies the community structure or core-periphery structure. Specifically, we applied the approach from Borgatti and Everett (2000) to estimate the fitness of core-periphery structure (degree of coreness). The estimating process started to place the nodes with the highest degree of coreness into the core and the rest nodes into the periphery. The process is iterated by continuously moving more nodes from the periphery to the core. The generation of centralization computed at each iteration was then used to produce a correlation coefficient (fitness) that decides the degree of core-periphery structure. We also tested the existence of community structure by computing the odds ratio that represents the subgroup salience (Frank 1995):

$$\theta_0 + \theta_1 \text{ same subgroup}_{ii'} = \log\left(\frac{p[w_{ii'} = 1]}{1 - p[w_{ii'} = 1]}\right)$$

where $w_{ii'} = 1$ when nodes i and i' are connected and 0 otherwise during the iteration. We used Gephi version 92 to complete the SNA and UCINET version 6.7 to complete the network analysis.

Results

Network Visualization

The sociogram [Fig. 2(a)] exhibits a community organization network with three subgroups. However, the sociogram [Fig. 2(b)] rejects a community structure because it does not demonstrate cohesive

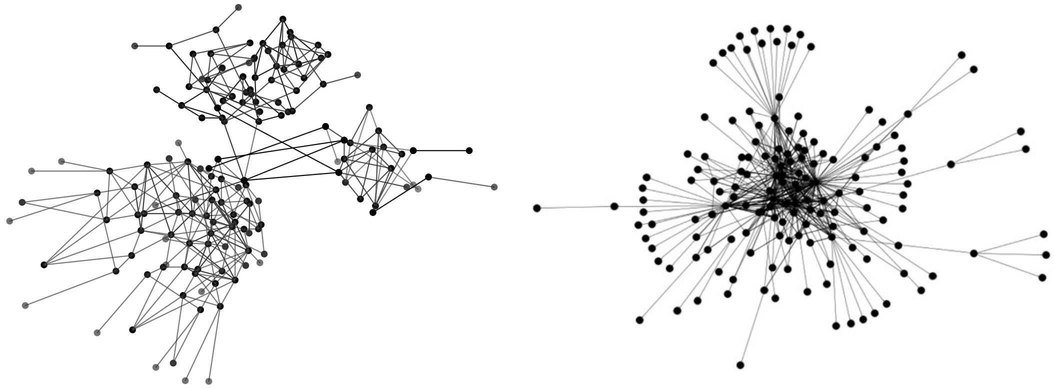

Fig. 2. Sociograms for (a) project organization network; and (b) project collaboration network.

subgroups or any cross-connections among the surrounding nodes. It indicates a core-periphery collaboration network with a concentrated core in the center. The nodes around the centroid are dense and their connections are compact, suggesting they are the core. The nodes in the surrounding area and their connections are loose, suggesting they are the periphery. Overall, network visualizations suggest fragmented project organization but integrative project collaboration.

Network Property Description

Table 2 lists the properties of the collaboration network and demonstrates a large set of stakeholders with 150 nodes and 603 ties. Some network properties are of interest. The network density (0.027) is not high, indicating a small portion of actual connections by potential connections. Although the network is complex, the diameter (5) is not high, indicating that the path of the two most distant nodes is cross only five project members. The average path length (2.421) echoes the observation, indicating that the members in the collaboration network are well connected. Overall, the network properties show a loose but highly connected collaboration network and suggest core members are tightly connected with other members.

Core-Periphery Structure Test

Table 3 lists the results of the core-periphery structure test on the collaboration network. The results indicate a promising core-periphery network structure (fitness $= 0.658$). Based on the network theory (Boyd et al. 2006), a core-periphery structure is identified when the coreness fitness is greater than 0.6. Also, the odds ratio in the clustering algorithms rejects any evidence of cohesive subgroups ($p = 0.5$) in the network. The size of the core accounts for less than 10% of total nodes. Specifically, the collaboration network has 12 core nodes (8.0%). The network properties for the core are greater than those for the periphery, suggesting that core members have more important network functions. For example, the degree centrality of the core is 56.583, indicating that each core member interacts with 56 project members. In contrast, the degree centrality of the periphery is 4.543, indicating that each periphery member interacts with average five other members. Overall, the network analysis supports a core-periphery collaboration network.

Table 2. Network properties

Property	Value
Size	150
Ties	603
Density	0.027
Diameter	5
Average degree	4.020
Average weighted degree	4.353
Modularity	0.342
Weakly connected components	2
Strongly connected components	96
Average clustering coefficient	0.409
Average path length	2.421

Network Configuration Analysis

Fig. 3 displays the core-periphery configuration for the collaboration network, where core members are scattered across subgroups of designer, contractor, and owner. The ties connecting core members are thicker, indicating that core members demonstrate tighter interactions than periphery members. For example, Node 56 from the designer subgroup is frequently connected with core members in the contractor subgroup (e.g., 195 and 235) and owner subgroup (e.g., 266 and 106). Overall, project members in the core are highly integrated across organizations, trades, and disciplines, and they maintain the shortest distance with other project members to streamline knowledge and information flows.

Network Pattern of Core Members

Table 4 lists the core project members including subgroup, expertise, and responsibility. The core members are from all three organizational subgroups and primarily have expertise in architectural design, engineering, management, and project needs (for client). In integrative project organizations, core members are associated with high responsibility, high technology, and high profile and rank. We do not find members with construction expertise in the core, and this is because construction activities are light in the schematic design phase. However, project members with construction expertise are critical for AEC projects and they should be in the core. Thus, we interpret that core members are very likely to be dynamic, and they rotate at different project phases depending on project schedule and priorities.

The network configuration indicates a dual-lead pattern for subgroups to effectively make decisions and diffuse information (Daft 1978). We have identified two key core members in each subgroup, who are a technical lead and a coordination lead. For example, in the designer subgroup, Node 97 is a technical lead and Node 56 is a coordination lead. The technical lead is responsible for decision making, and the coordination lead is responsible for supporting technical lead and facilitating knowledge diffusion among core members

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Table 3. Results of core-periphery tests

Property	Collaboration network		
	Core	Periphery	Ratio
Node numbers	12	138	0.09
Node percentage (%)	8.0	92.0	0.09
Density	1.061	0.006	176.83
Degree centralization	56.583	4.543	12.45
Betweenness centralization	914.423	10.804	84.64
Closeness centralization	0.525	0.176	2.98
Eigenvector centralization	0.590	0.096	6.15
	Core-periphery structure		
Fitness	0.658		
Core nodes	13, 56, 97, 104, 106, 135, 191, 195, 219, 235, 266, 340		
Periphery nodes	1, 5, 6, 10, 11, 21, 25, 26, 37, 40, 41, 45, 46, 58, 60, 62, 66, 74, 77, 79, 86, 87, 88, 93, 128, 134, 136, 145, 146, 147, 148, 150, 158, 159, 160, 167, 169, 179, 185, 186, 193, 201, 214, 217, 218, 220, 236, 237, 242, 251, 258, 260, 269, 271, 272, 273, 275, 278, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 296, 297, 298, 299, 301, 302, 303, 304, 306, 307, 308, 309, 311, 313, 314, 315, 319, 320, 324, 327, 328, 329, 330, 333, 334, 336, 337, 338, 339, 342, 343, 344, 345, 347, 348, 349, 350, 351, 352, 353, 354, 356, 357, 358, 360, 361, 362, 365, 366, 368, 369, 370, 371, 372, 373, 374, 376, 379, 380, 381, 382, 383, 385, 386, 387, 388, 391, 398, 407		

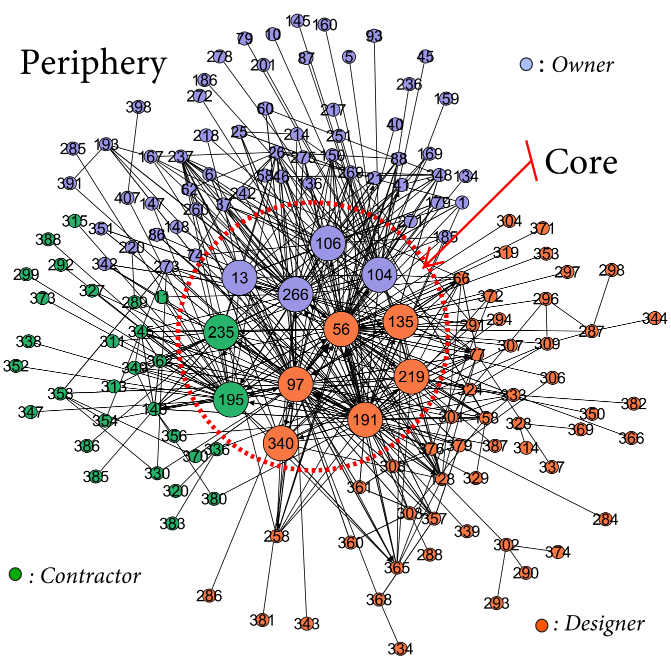

Fig. 3. Core-periphery structure for the project collaboration network.

within subgroup and with other subgroups. Technical and coordination leads should stay active in collaboration network to maintain a balanced information load. Our follow-up interviews also support this finding of dual-lead pattern, quoted as follows:

> Project managers always fill in the holes in the communication network whether it is technical, or coordination need for communication. If we can prepare ahead for such situations, we can be better off at each project. This is most in-depth conversation I have ever had in industry in probably five years. I have talked to colleagues linking about things we do processes wise to improve process, but nothing involves other parties. So it is just interesting.

Supplemental Analysis for Validation

Based on a triangulation strategy, we validated our findings using supplemental data analysis. We analyzed the direct collaboration network using email data only from senders (From) and direct recipients (To) because emails copied to (CC) are indirect recipients. The direct collaboration network with 122 members and 408 ties also has the core-periphery structure (fitness $= 0.683$). Fig. 4 shows high similarity between this collaboration network and the one previously reported. The correlation coefficient of the network property from the two collaboration networks is 0.999 ($p < 0.01$). Further, the pairwise t-test ($t = -1.299$ and $p > 0.05$) and Wilcoxon test ($W = 18.500$ and $p > 0.05$) reject significant difference. The core/periphery ratios on the two collaboration networks are not different ($t = -1.477$ and $p > 0.05$), indicating similar core and similar periphery.

All 11 core members in the direct collaboration network are overlapped with the 12 core members in the collaboration network. The only exception is Node 340, a civil engineer from the designer subgroup. The civil engineer has sent a considerable amount of CC emails to the designer subgroup manager (Node 56) and received a considerable amount of CC emails from the chief architect (Node 191). We postulate that the civil engineer has close and direct collaboration with the technical lead (97) in the designer subgroup about specific technical issues and they must receive updates from the chief architect and report the progress to the design manager. The civil engineer's interactions with the chief architect and design manager are indirect. Overall, the collaboration of project members is highly integrated across subgroups, trades, and disciplines.

Discussion

Implications for Integrative Collaboration

This study has confirmed the discrepant alignment of organization network and collaboration network in AEC projects. The finding indicates the existence of integrative collaboration in fragmented project organizations. The outcomes provide three implications for scholars and practitioners to better understand and implement integrative collaboration, especially in fragmented project organizations.

First, organizational integration is not a must to achieve integrative collaboration. The finding provides a better understanding of the relationship between integrative organization and collaboration, which remains challenging for the AEC industry (Zhang et al. 2013). The literature asserts that organizational integration is a means to foster integrative collaboration (Wen and Qiang 2016). That is, the goal of organizational integration is to conduce effective collaboration behaviors and therefore high project performance. Our findings demonstrate that project organization does not always determine project collaboration. In other words, fragmented project organization is not always a barrier to integrative collaboration behaviors. The implication echoes a study about organizational architecture—the interplay between formal authority network and informal information network—namely that they generate a positive performance

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Table 4. List of project members in the core

Node	Subgroup	Expertise	Responsibility
13	Owner	Project needs and program	User group representative. Responsible for conveying the requirements and needs of future users to the project team and ensuring coordination between them.
56	Designer	Management	Project manager and coordination lead of the designer. Responsible for coordination between designer, owner, and contractor for project design, budget, and schedule interaction.
97	Designer	Architectural design	Technical design lead of the designer. Responsible for the coordination between design and constructability issues and ensuring collaboration between the engineering consultants and the design team.
104	Owner	Mechanical	Mechanical designer from owner as a consultant. Responsible for overseeing the mechanical design and ensuring the design complies with the institution's standards.
106	Owner	Project needs and program	Director of the user group. Responsible for overseeing all the processes and ensuring the project fulfills the requirements such as design, budget, schedule, and quality.
135	Designer	Mechanical	Mechanical design lead/consultant.
191	Designer	Architectural design	Design lead of the project. Responsible for designing based on the client's needs, maintaining design intent, and ensuring the work of other parties comply with the architectural design.
195	Contractor	Management	Project manager of the contractor. Responsible for constructability, budget, and schedule.
219	Designer	Architecture	Architectural designer. Responsible for preparing architectural drawings.
235	Contractor	Management	Project director of the contractor. Responsible for the coordination between the contractor and the other parties.
266	Owner	Management	Project manager of the owner. Responsible for ensuring that the project fulfills the owner's requirements and needs.
340	Designer	Civil engineering	Civil engineer working on the earthwork and site utilities.

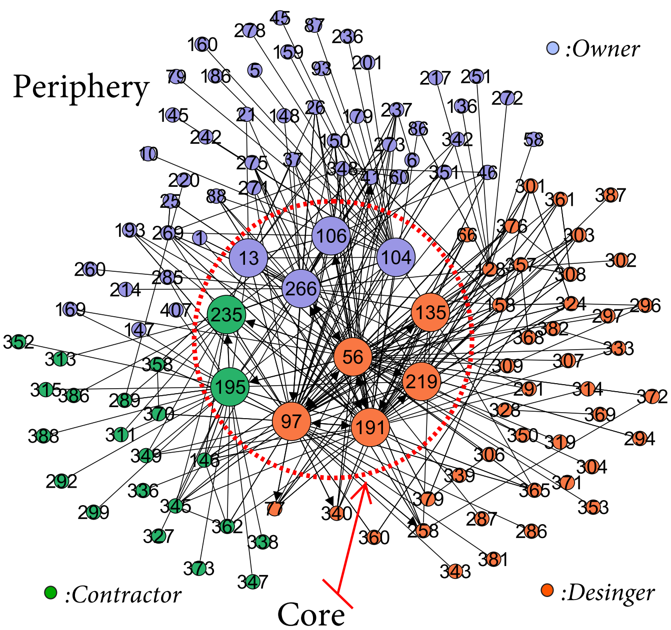

Fig. 4. Core-periphery structure for the direct collaboration network.

effect on project members when their configurations are consistent (Soda and Zaheer 2012).

Second, the dual-lead pattern facilitates integrative collaboration. The pattern refers to two centers in organizations: a technical core and an administrative core (Daft 1978). Each core has its own goals, problems, activities, expertise areas, and participants. Our finding implies that the dual-lead pattern facilitates integrative integration, where the dual-lead technical lead focuses on technical issues in design, engineering, and business, and the coordination lead streamlines information flows within its own subgroup and across other subgroups. Additionally, the coordination lead also needs certain professional expertise to understand and interpret technical issues. Our findings advocate the dual-lead pattern for each subgroup and suggest that technical lead and coordination lead buffer each other and collectively maintain a balanced workload to ensure integrative collaboration across subgroups.

Third, core members in project collaboration may not have high profiles in the project organization. Integrative collaboration networks contain core members and periphery members. However, the core members in project collaboration can be either a high-profile or non-high-profile in project organization. A project member's collaboration position is not totally reliant on the member's organizational rank. That is, a high-profile individual in a project organization (e.g., director) cannot secure a core position in the project collaboration. Similarly, a non-high-profile actor in a project organization can function as core in project collaboration.

For example, a core member in collaboration in our case is a mechanical engineer who works as a consultant for the owner. Unlike studies that encourage knowledgeable members to move to the core (Huckfeldt et al. 2014), we highlight core members whose expertise and responsibility fit project needs. This finding recommends two practical strategies: (1) project management should respect non-high-profile members and recognize their importance to integrative collaboration, and (2) project management should encourage non-high-profile members to proactively function as cores.

Implications for Information Sharing

Our findings provide practical implications for effective information sharing in collaboration. First, information sharing streamlines knowledge diffusion hierarchies. Extant research highlights that knowledge diffusion is an essential organizational ability to facilitate expertise integration (Javernick-Will 2012) and team integration (Wen and Qiang 2016). Knowledge diffusion occurs through information sharing among project members. Our finding characterizes the hierarchical structure for information sharing occurrences. The structure influences knowledge diffusion. Based on the network theory, a centralized network improves the efficiency of knowledge sharing and promotes decision quality, whereas a decentralized network improves the robustness of knowledge sharing and prevents mistakes (Du et al. 2019). It implies that integrative collaboration should consider information accuracy and completeness, both of which moderate network functions. Overall, project management should use precautions to ensure periphery members receive prompt and unambiguous information, for example, through centralized information systems.

Second, the wise use of carbon copy facility (CC) in emails improves information sharing. The CC facility is extensively used with three functions: (1) encourage reliable and collective decision making, (2) bring people to witness events, and (3) report or document message threads. Compared with the To recipients, CC recipients often play a witness role and may never actively participate in communication. The To recipients are called active communicators and the CC recipients are called witness communicators. Our findings demonstrate that CC emails do not harm integrative collaboration. Instead, CC use enables information sharing to periphery members and allows them to share accountability across all project members (Gimenez 2006).

The downsides are that CC emails may move additional witness communicators to the core and they do not contribute much to the problem-solving, e.g., Node 340 in our case. CC recipients may also be overloaded and have to ignore information, resulting in "information bankruptcy" (Whittaker et al. 2007). Overall, our findings recommend project-level email policies to guide information sharing, for example, using colors distinguish importance (Soucek and Moser 2010). Core members appear to be able to diffuse important information and facilitate coordination, but with possibly a high demand on their time and interactive capacity.

Conclusion

AEC project organizations are fragmented with subgroups such as designer, contractor, and owner. Current practices advocate organizational integration to seek integrative collaboration. This study contributes to the knowledge of organizational theory. Our findings identify the discrepant alignment of the configurations between organization network and collaboration network in AEC projects and indicate that organizational integration is not a must to achieve integrative collaboration.

This study also contributes to engineering management practice. Our findings provide implications for integrative collaboration in fragmented project organizations. First, efforts toward integrative collaboration should focus on collaboration behaviors rather than project organization. Second, subgroups should adopt the dual-lead pattern (i.e., a technical lead and a coordination lead) to facilitate integrative collaboration. Third, project management should encourage non-high-profile members to functions as cores. Fourth, project management should ensure information sharing with periphery members and prevent information overload.

Limitations exist in this study, and they can be addressed in future research. First, the core-periphery collaboration network was identified in the project design phase. This network structure may not apply to other project phases. The network structure is likely to be dynamic along with project progress. Future research can use data from other project phases to examine the consistency between organization and collaboration networks. Second, this study only confirms integrative collaboration in fragmented AEC project organizations. Future research can extend our work and explore configurations of project collaboration networks in integrated organizations such as IPD projects. Third, our findings do not generalize that all fragmented project organizations have integrative collaboration. Factors such as project location, management culture, and project contexts may mediate collaboration network configurations.

Data Availability Statement

Part of the data, models, and codes that support the findings of this study are available from the corresponding author upon reasonable request.

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