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The effects of organizational divisions on knowledge-sharing networks in multi-lateral communities of practice

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Knowledge is a fundamental resource for project-based organizations, and it resides within individual employees. By dividing employees according to their abilities, job roles, and areas of expertise (e.g. business units, functional disciplines), managers create groups within the organization without seeing the impact on underlying knowledge flows. Knowledge sharing across business units and disciplinary groups can produce immense benefit, yet anecdotal evidence suggests that these groups produce 'silos' that limit connection between people across the organization. Although communities of practice (CoPs) have recently emerged as a mechanism to encourage practice-based knowledge sharing across organizational silos, it is not clear if the influence of business units and disciplinary groups has a similar effect on knowledge sharing within CoPs. There are few studies that quantitatively assess the impact of organizational structures on informal knowledge-sharing networks. To clarify this anecdotal evidence, this study analyses more than 1600 knowledge-sharing connections in two CoPs using a statistical resampling technique to determine whether informal knowledge-sharing networks are constrained by business units and disciplinary groups. Results show that in the first CoP, knowledge-sharing connections were constrained by business units, with few connections existing between business units. In the second CoP, knowledge-sharing connections were constrained by disciplinary groups. In our discussion of these findings, we evaluate the applicability of the term 'community of practice' to manager-initiated knowledge-sharing groups, and discuss how formal structures created by management produce differential opportunities to connect that influence network structure within CoPs.

Keywords: Communities of practice, knowledge management, organizational boundaries.

Introduction

Knowledge management is one of many complex problems facing multinational construction and engineering organizations as they seek to design and build projects. As many firms have realized, the collective knowledge of their employees is a strategic resource of equal value to financial capital (Grant, 1996), and the key to capturing this value is the social networks that serve as a conduit for knowledge (Chinowsky *et al.*, 2009). Traditionally, organizations manage employees, in part, by creating structures to group employees by industry (e.g. business units) and discipline. Both of these groupings are *epistemological* in nature, meaning that they delineate different domains of knowledge. Unfortunately, group membership in these structures can rapidly become a boundary that restricts knowledge flows within the company, isolating expertise to a particular industry or disciplinary setting. Restricted knowledge flows, also known as 'silos', lead to conditions in which construction companies repeat mistakes across projects, fail to learn from innovation occurring elsewhere in the company, and dedicate resources to solving problems which have already been addressed within the organization (Javernick-Will and Hartmann, 2011). In other words, silos are a

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'suboptimal organizational construct' that can limit the productivity and quality of projects (Yuventi *et al.*, 2013).

Over the past several decades, communities of practice (CoPs) have emerged as a potential solution to this problem. CoPs originated as close-knit groups that emerge through the social interaction of everyday activity (Lave and Wenger, 1991). More recently, literature has suggested that these organically emergent groups can be cultivated and grown to include many different subgroups (Wenger *et al.*, 2002). In line with this trend, project-based organizations frequently initiate CoPs for the express purpose of sharing knowledge throughout the company. Manville and Foote (1996) provided a succinct definition of a CoP as:

> a group of professionals informally bound to one another through exposure to a common class of problems, common pursuit of solutions, and thereby themselves embodying a store of knowledge.

The impact of CoPs can be enormous within project-based organizations. When professionals are united across the company in terms of common problems that they face, each project execution becomes an opportunity to apply the best of what the company knows to the project at hand. Because these companies perform projects in diverse markets, this learning process can provide a competitive advantage if knowledge is exchanged between various projects and knowledge bases (Kogut and Zander, 2003; Javernick-Will and Levitt, 2009; Javernick-Will and Scott, 2010). Although each project, industry, and discipline is unique, there are common processes, lessons learnt, and project management expertise that apply across multiple business lines and disciplines. CoPs bring together knowledge workers in such a way that they are able to share their experiences and lessons learnt with others who face similar problems, thereby working, learning, and innovating as part of a global community of practitioners (Brown and Duguid, 1991).

In practice, however, managerial trends have shied away from cultivating existing CoPs in favour of a higher degree of control. Rather than trust that CoPs will emerge that are serendipitously aligned with the goals of the organization, managers wish to strategically leverage knowledge sharing to generate value (Saint-Onge and Wallace, 2012). Thus, many managers create large CoPs with a membership that spans multiple disciplines and business units, in the hope that socially based knowledge sharing will organically occur, thereby creating consistency of practice and generating innovation across these formal organizational groups (Wenger *et al.*, 2002). Because these CoPs span multiple dimensions of different knowledge (i.e. business units and disciplinary groups), we refer to them as *multi-lateral.* Within CoPs, employees can connect with one another regardless of formal organizational groups or reporting structures, and therefore have the freedom to meet their individual knowledge-sharing needs. The topical focus unites business units and disciplinary groups by channelling discussion towards common problems and solutions, rather than contextual differences. In the past few decades, CoPs with this goal have become commonplace in project-based organizations trying to increase knowledge sharing.

It is common to create and launch CoPs, although it is a significant deviation from the original 'emergent' model of CoPs that has been proposed by many theorists (Brown and Duguid, 1991; Lave and Wenger, 1991; Wenger and Snyder, 2000; Wenger *et al.*, 2002; Kimble and Hildreth, 2004; Lindkvist, 2005; Roberts, 2006). This has led to broad criticism regarding the application of the term 'community of practice' to knowledge-sharing groups initiated by managers (Amin and Roberts, 2008), and scepticism that these loosely bound groups would operate independently from the existing structures of the organization (Roberts, 2006). At the same time, most of this criticism has relied on theoretical arguments, due to a lack of empirical network data. Fundamentally, the effects of formal business units and disciplinary groups on knowledge-sharing networks within manager-initiated CoPs are unknown.

Point of departure

The purpose of this research is therefore to determine whether business units and functional disciplines constrain knowledge flows within knowledge-sharing networks in global CoPs. Because knowledge is intangible, it is difficult to monitor and track (Liebeskind, 1996), so that informal networks consisting of relational connections between employees are largely invisible. Thus, we seek to answer the question: *To what degree do business unit and functional discipline boundaries fragment informal knowledge-sharing networks within multi-lateral CoPs?*

To fill this gap, we empirically investigate knowledge-sharing connections between organizational groups in two multi-lateral CoPs. Specifically, we analyse whether organizationally imposed business units and disciplinary groups create silos in informal knowledge-sharing networks. We employ a social network approach to observe, analyse, simulate, and visualize knowledge-sharing network structures. Using statistical resampling, we quantitatively determine the degree to which individual business units and disciplinary groups limit knowledge-sharing networks within multi-lateral CoPs. Ultimately, we wish determine if manager-initiated CoPs are able to span existing organizational groups, or if business units and functional disciplines inherently limit knowledge flows within their domains.

Business units

While the title (e.g. business units, business lines) and scope (e.g. type of contract/client, sector of project) vary from company to company, nearly all construction and engineering companies group employees according to project type or economic sector. Business units are knowledge-based divisions with distinct sources of knowledge and expertise. From this idea, previous work has found that business units with central network positions (and thus more access to different knowledge bases) perform better. Similarly, other studies found that creativity and innovation are fostered when knowledge is shared, or recombined, between business units (Tatum, 1989; Leonard-Barton, 1995; Hargadon and Sutton, 1997). This work theorizes that new ideas and more rapid improvement would result from increased knowledge sharing between business units.

While inter-business unit knowledge exchange can lead to new ideas, the distinct knowledge bases can create communication problems and thus is seen as a simultaneous source and barrier to innovation (Carlile, 2002). Perhaps the greatest danger of poor knowledge flows between business units is that each business may be trying to solve similar problems, and are dedicating resources to problems that have already been solved within the organization (Carrillo and Chinowsky, 2006).

In sum, classifying employees into different business units helps to delineate what employees know by specifying the type of project they typically work on. Business units represent differing knowledge bases that can share knowledge of specific project types. However, this organizational classification may also cause business units to become siloed from one another, and thus, not gain the benefits from knowledge exchange across the organization.

Disciplines

In addition to business units, many multinational project-based organizations group employees by specialty or function to differentiate, for example, between civil and electrical engineers. These divisions group together people with similar expertise to form knowledge bases within the firm. Past studies have found that each disciplinary group has a different perspective (Boland and Tenkasi, 1995), and that the interpretive schemes that people use in the workplace are determined heavily by their functional or departmental 'thought worlds' (Dougherty, 1992). In the construction literature, this sentiment is echoed as research claims that different disciplines develop their own language consisting of the use and understanding of specialized terminology (Fong *et al.*, 2007).

Consistent with prior research on different knowledge bases, heterogeneity in disciplinary perspectives can easily lead to communication barriers (Bechky, 2003), and failures of interpretation due to a lack of mutual understanding (Cramton, 2001). In fact, most studies explicitly frame inter-disciplinary knowledge exchange as difficult because each discipline has a unique knowledge base. Communication between disciplines can therefore pose a 'translation' issue. At the same time, there can be individual- and project-level benefits to inter-disciplinary knowledge sharing (Cross and Cummings, 2004; Cummings, 2004), and crossing disciplinary boundaries can lead to the production of new knowledge through novel re-combination of existing ideas (Alin *et al.*, 2011).

Similar to business units, disciplinary divisions clearly represent distinct knowledge bases that help the company organize. While sharing between different disciplinary knowledge bases is difficult, it can also add value and productivity for a firm.

Research approach

Research setting

To conduct this research, we selected two CoPs within two different multinational construction and engineering companies. Within each of these CoPs, knowledge sharing between organizational divisions was not inhibited in any way; rather, all members were on equal standing to help solve problems.

Although there is significant debate surrounding the applicability of the term 'communities of practice' to manager-initiated groups, the CoPs selected for this study fit several criteria that are consistent with prior management theory. Because this study is focused on the business practice of using CoPs as a mechanism to manage knowledge, we draw from the practice-based model of CoPs provided by Wenger *et al.* (2002). By this model, CoPs are structures that have three elements: a domain of knowledge, a community of people, and a shared practice that is being developed. First, each CoP has an established domain of knowledge established through a topical boundary. The members of each CoP are engaged in knowledge-intensive work, and belong to the CoP because they have an interest in the expressed topic (domain) of the CoP. Because they face a common class of problem (such as applying computer-aided design (CAD) to projects), they are not so different that there are problems with 'translation' between two completely different fields of work (Bechky, 2003). Membership to these CoPs is controlled by a subscription list, but participation in the CoP is voluntary, and therefore indicates an interest in the knowledge domain. Because this membership is clearly defined, we were also able to select communities whose membership spanned both business units and functional disciplines, providing the diversity required to analyse organizational divisions within the same CoP. Second, both CoPs must have an element of *community,* which is difficult to define. Both are driven by volunteerism, and are more 'loosely connected, informal, and self-managed' (Wenger *et al.*, 2002, p. 41) than business units and functional disciplines. Each has a membership that actively participates in the CoP on some level. Prior to the study, this was evaluated on the basis of visible participation in an electronic platform; however, the social network design of this study means that we partially evaluate the degree to which members 'interact regularly on issues important to their domain' (Wenger *et al.*, 2002, p. 34). As an additional note, CoPs are not limited in size as long as it provides the opportunity to learn while embedded within a social context (Brown and Duguid, 1991; Lave and Wenger, 1991), maintains a specific and defined knowledge base which constitutes a 'common class of problems' (Manville and Foote, 1996), and elicits participation from its members. This means that the networks can be large enough to display significant trends to determine whether organizational divisions constrain informal networks. Finally, each CoP has an established *practice,* which includes the socially acceptable ways of doing things, common approaches, shared understandings, and resources that provide a basis for action. The practice of each CoP is captured in both concrete and explicit documents, as well as less tangible behaviours and perceptions.

The two CoPs selected for this study each have a domain, demonstrated elements of community, and a set of documents and behaviours that can be considered a practice. Because the CoPs are housed in two different companies, each one has different terminology for classifying business units, and disciplines although the fundamental concepts are the same. These CoPs are discussed more in depth below. Throughout this paper, business units and disciplines are referred to as divisions, while the specific units, disciplines, and levels (i.e. Water Resources Engineering, Contracts, etc.) are referred to as groups. In some cases, we do not have group data for all employees, forcing us to exclude individuals from the networks. In these cases, the reduced number of network participants is reported in parenthesis.

Process Improvement CoP – Company A consists of more than 50 000 employees in more than 40 different countries. The company has grown organically through a long history of construction megaprojects, and is divided into five distinct markets, each of which forms a formally defined business unit. Although each business unit is run as a separate profit centre, management wants knowledge to flow across the entire company, as evidenced by employee mobility to different business lines, and several multilateral CoPs. Within this context, the Process Improvement CoP is a group of 273 process improvement professionals acting as internal consultants for individual projects. Of the 273 members, we were able to capture grade-level data for 271 (99%). There were no missing data in regard to business units in the Process Improvement CoP, and 96% of the 273 members are represented in 5 business units: Government services (29%), Power (25%), Oil Gas & Chemical (17%), Civil (15%), and Mining & Metals (11%). Within the Process Improvement CoP, 20 different disciplines are represented, although 83% of the 273 members are captured in 8 disciplinary groups. These include Engineering (28%), Project Controls (16%), Field Supervision (15%), Field Engineering (9%), Project Management (8%), Procurement (7%), Quality Assurance (5%), and Contracts (4%).

Domain: Employees in the Process Improvement CoP were individually selected and trained in Six Sigma. Thus, the topical knowledge domain is focused around using Six Sigma methodologies to improve processes on projects.

Community: The membership list of the PI CoP is defined through training certification. Individuals seek nominations into the programme where they are trained together, often forming tight social bonds. Although membership comes from a formalized training process, the Process Improvement CoP is still driven by volunteerism because employees are not required to participate in the knowledge-sharing activities which define the CoP. During training, individuals are introduced to a number of knowledge-sharing tools by which they can connect with one another and read about completed process improvement projects. Using these tools, CoP members can choose to share best practices, success stories, and project ideas that could potentially be used in other areas of the company. After training, members participate in community through an electronic platform (formal knowledge management system), face-to-face meetings, informal interactions, common task assignments, ongoing training (top down), and community awards (formal benchmarking). The complex array of interactions within the PI CoP, therefore, contains elements of self-organizing, technocratic, and best practice systems (Kasper *et al.*, 2013).

Practice: Members are constantly developing new tools, reviewing past process improvement projects, and working to determine their role in the organization. The practice is therefore focused on using an established set of methodologies, behaviours, and world views to perform process improvement work.

CAD CoP – Company B consists of more than 40 000 people in 150 countries. The company has grown rapidly through aggressive acquisitions, and currently has operations in numerous business sectors (i.e. energy, transportation, etc.) and functional areas (i.e. consulting, planning, etc.). The CAD community exists within Company B as a collection of 1152 CAD draftspersons, engineers, and managers. The CAD CoP spans 10 different business units, 6 of which capture 90% of the 1152 employee population. These business units include Transportation (33%), Water (18%), Building Engineering (16%), Planning Design & Development (16%), Environment (4%), and Minerals & Industry (3%). Company B did not have a formal record of employees' functional disciplines, although they do have more formalized functional groups, so the question was included in the survey and is therefore subject to response rates. Because of this, we only captured disciplinary data for 489 (42%) members of the CAD population, where there are 20 different disciplinary groups represented. Of these, eight disciplinary groups capture 82% of the known disciplinary classifications. These eight are Civil Engineering (20%), Structural Infrastructure (15%), Transportation Engineering (11%), MEP Disciplines (11%), Architecture (10%), Water Resources Engineering (6%), Drafting (5%), and Electrical Engineering (5%).

Domain: The CAD CoP was chartered to bring together employees concerned with the use of CAD software. This includes managers, drafters, technicians, and support personnel using AutoDesk products, Microstation products, Revitt, and BIM software.

Community: The basis for the CoP is an online knowledge-sharing platform that allows members to freely join and share problems that they are working on. Using this platform, CoP members exchange global CAD practices and standards, share templates, and discuss CAD issues. Interactions are not limited to the online platform, however; members interact locally with other CAD workers, share project tasks, and occasionally travel for work rotations, collaborative projects, conferences, and trainings. In contrast to the PI CoP, the CAD CoP is primarily facilitated through bottom-up informal personal networks and the online sharepoint system. There is, however, a global CAD council that facilitates personal exchanges between top managers. Thus, the CAD CoP facilitates exchange through self-organizing as well as technocratic systems, but lacks the formal benchmarking that characterizes best practice knowledge management (Kasper *et al.*, 2013).

Practice: The CAD CoP has a strong body of practice around drafting and modelling that includes specific tools, with their requisite struggles and intricacies, as well as a particular role within the company. CAD workers understand themselves as undervalued, behind the scenes workers whose skills and tools are rapidly coming to the forefront of design and construction. As a result, their practice is very focused on technological progression, advancement of technical skill, and a rapidly changing work environment.

Data collection

A social network perspective is an excellent platform to examine the interaction of formal organizational structures and informal relationships between members of the organization (Chinowsky and Taylor, 2012). To assess the degree to which formal organizational divisions constrain informal knowledge-sharing networks, we used social network analysis (SNA), which enables us to graphically portray network relationships (Moreno, 1960). SNA is particularly useful for examining patterns of relationships, and can be used in such a way that network structures are evaluated by the number of connections within and between differently sized groups (White *et al.*, 1976). Social network methods are a relatively new approach to research in project-based organizations, although they have been gaining popularity in recent years because of their ability to describe underlying relationships (Chinowsky and Taylor, 2012). Furthermore, by assuming *knowledge-sharing connections* as the unit of analysis instead of discreet exchanges, this study adheres to a view of knowledge as socially constructed, rather than an object for exchange (Noorderhaven and Harzing, 2009).

For this reason, we use a social network survey methodology to capture knowledge-sharing connections between employees in a defined community. Social network surveys include person-centred questions, which capture individual demographic attributes such as level of education or prior geographic work locations, a network identification question, and network questions regarding characteristics of connections, also known as dyads. Because of our specific interest in knowledge-sharing connections, the network identification question asked participants 'with whom have you exchanged knowledge on job related practices in the past 6 months?' We further specified the type of exchange as CoP-specific knowledge which includes 'any practice-oriented knowledge that is required for you (or those with whom you interact) to perform job related tasks. "Practices" can be project related or organization related'. Participants were allowed to select their knowledge-sharing connections from a pre-defined list of all other identified CoP members. At this point, it is important to clarify the definition of knowledge used in this study. Because we focus on *knowledge-sharing connections* rather than discreet interactions, we are capturing social patterns of interaction that are focused on job-related tasks. For the sake of data collection, 'knowledge exchange' is portrayed as an activity where an objective commodity is exchanged (knowledge). This reduces the need to explain to study participants the theoretical nuances of defining knowledge, while simultaneously capturing the *practice* of interacting with others surrounding a particular knowledge domain. Due to the inherent limitations of surveys in creating clear constructs, we followed up with 5–10% of the CoP population using phone interviews, and validated a sample of knowledge-sharing connections from the survey. For the validated connections, we identified that discreet interactions within a given relationship are sharing knowledge, rather than information or data (Alavi and Leidner, 2001), and that the relationship constituted ongoing social interaction. Overall, 93% of the connections from the survey were validated, providing a high degree of confidence in our knowledge-sharing connection construct.

As noted above, we obtained business unit data for all community members from each respective Human Resources (HR) department. Data for functional disciplines were obtained from HR for the Process Improvement CoP, but had to be included as a survey question in the CAD CoP due to limitations in the HR data set. The disciplinary responses were then grouped by community managers into disciplinary categories that reflected cohesive groups within the CoP.

Several days before deploying each survey, the community leaders sent an email to CoP members inviting them to participate in the survey and giving them instructions on how to use the NetworkGenie online survey interface. During survey deployment, each employee in the CoP received a personalized email with a unique login ID and password to complete the survey. Surveys were left open for 4–6 weeks to increase response rates, during which community members were sent several reminder emails. When the survey was closed, 100 people had responded within the Process Improvement CoP, representing a 36.6% response rate and 483 people had responded to the CAD CoP, representing a 41.9% response rate.

Network assessment and silos

Using NetMiner, a social network analysis software, we created blockmodels based upon the organizational divisions for each CoP. A blockmodel is a square matrix that displays the number of connections within and between different groups (White *et al.*, 1976). In a blockmodel, the rows and columns are group names, and each cell in the matrix represents a specific relationship. For instance, when the Process Improvement CoP was sorted by business unit, the row and column headers would display the names of each business unit. Within the cells, the number of knowledge-sharing connections between two groups (i.e. Civil Business Unit to Water business unit) is counted and tallied in the appropriate cell. As a result, the diagonals represent connections that occur within each business unit, while the other cells represent relationships between business units. As an example, Table 1 displays a block model for the Process Improvement CoP organized according to business units. In the first column, there are 61 knowledge-sharing connections between employees in the Government Services business unit, but only 4 connections going from the Civil business unit to Government Services.

Networks can be a powerful tool for examining relationships, although each network is unique (e.g. density, degree distribution, clusters, etc.), so there is no definitive benchmark by which to compare networks to each other. This poses a problem when we try to conduct cross-case analysis. To address this problem, network researchers create a comparative baseline using two main methods: simulation and statistical resampling. Exponential random graph modelling (ERGM) is perhaps the most widely used simulation tool in network research. It works through generating

Table 1 Blockmodel of process improvement CoP by business unit

	Gov. service	Civil	Mining & metals	Oil gas & chemical	Power
Gov. service	61	1	1	1	1
Civil	4	84	3	2	7
Mining & metals	1	1	132	3	6
Oil gas & chemical	1	1	1	51	4
Power	5	5	1	6	121

connections according to a known set of assumptions, such as preferential attachment (higher probability of connection to the person with the most connections). In contrast to ERGM, methods based on statistical resampling like relational contingency tables (Borgatti *et al.*, 2002) generate a simulated population of networks by holding constant important network properties, but altering the base assumptions within the network. For instance, if we know that there are 40 connections within the civil business unit, we would like to know how many connections we could *expect* if business units were not associated with how individuals chose to connect with one another. Thus, the goal of our simulation is to hold constant as many network properties as possible, but simulate a null condition in which business units and disciplinary groups are independent of patterns of connection. For this reason, we hold constant the number of connections in the network (e.g. 640 connections in the PI CoP), number of groups (e.g. 5 Business Units in PI CoP), and number of people within each group (e.g. 273 people in PI CoP, 27% in government services business unit, etc.), and then simulate new networks by randomly pairing network members with a business unit or functional discipline. The result is an expected number of connections for each relationship in the blockmodel (connections according to disciplinary group or business unit), where the expected number of connections is based on the assumption that there is no association between organizational divisions and patterns of connection. Furthermore, we generate a histogram that serves as a random sampling distribution for each cell in the blockmodel by aggregating the simulated number of connections over 10 000 iterations. These generated distributions provide a point of reference to the number of ties observed (based upon responses to the questionnaire). With this point of reference, we can claim whether a particular relationship is higher, lower, or relatively close to an expected value. Resampling techniques such as this one are common in statistical methods for cases when the underlying distribution of values is unknown (Efron and Efron, 1982). To accommodate these simulations, groups were excluded from the analysis if their average expected number of within group connections based on 10 000 iterations was less than one. This cut-off was determined because knowledge-sharing ties are integer values, so expected frequencies less than one have no practical significance.

With the simulated random sampling distributions, we use error tolerances of $\alpha = 0.05$ for both the upper and lower tails. For each potential relationship within or between a group, observed values that fell in the 95th percentile (observed is much larger than expected) of the random distribution were classified as *strong levels of connection*, visualized as a bolded tie between two groups. This reveals whether there are far more connections than we would expect, giving a reasonable degree of confidence that there are more than enough knowledge-sharing connections to equitably share knowledge for that particular relationship. Next, observed values that fell in the bottom 5% (observed far less than expected) of the random distribution were classified as having *no connection*, visualized by no tie between two groups. Because the observed values are significantly lower than the expected values, we expect that knowledge flow is limited for that particular relationship due to a lack of connections. Finally, those ties that fell in the middle 90th percentile are simply *normal levels of connection,* and are visualized through a non-bolded tie. This is summarized in Table 2.

On a network level, a single business unit or discipline may be isolated, yet the network as a whole is not considered ‘silo-ed’. Because of this, we created a scale based on majorities to assess the degree to which silos occur on a network level. If, for instance, every business unit displays strong internal ties, we classify this network as being ‘completely constrained’ because knowledge flows are contained within business unit groups. As the degree of constraint increases, the organization has a higher risk of developing harmful knowledge-based silos. This scale is detailed in Table 3.

Table 2 Connection visualization

Classification	Definition	Visual representation
Strong levels of connection	The observed number of connections is in the 95th percentile of the simulated random sampling distribution (observed >> expected value)	Bolded tie
Normal levels of connection	The observed number of connections is in the bottom fifth percentile of the simulated random sampling distribution (observed << expected value)	Normal tie
No connection	The observed number of connections is in the middle 90th percentile of the simulated random sampling distribution (observed ≈ expected value)	No tie

Table 3 Network-level constraint classification

Classification	Description
No constraint	Normal or strong ties exist among all groups; represents the ability of the informal network to distribute knowledge equitably
Weak constraint	Some groups have strong internal ties, displaying a preference for sharing knowledge internally, but the majority of groups have normal levels of internal ties
Strong constraint	The majority of groups have strong internal ties, displaying a preference for sharing knowledge internally
Complete constraint	Every group has strong internal ties, displaying a preference for sharing knowledge internally; there are no ties between groups

Results

A network diagram was generated for business units and functional disciplines in each community. As a general guide, each diagram displays the network within a CoP based upon one division (business units are displayed in Figures 1 and 2, disciplinary groups are displayed in Figures 3 and 4), where nodes are the individual groups that belong to that particular division, and the links reflect the strength of a given connection *relative to the randomly generated network*. By displaying the *relative* strength of these ties, we mitigate the effects of different group sizes. Circular ties, which point at their node of origin, show the relative number of connections within a group, instead of between groups. In the caption of each visualization, both the number of people (n_p) and the number of individual ties (n_t) are recorded to show the size of each CoP, and to report our relative sample sizes. For ease of reporting, the networks have been symmetrized according to the highest number of ties, so these networks are not directional in nature. Although business units and disciplinary groups appear to be topically aligned in several instances, we performed a cross-tabs analysis

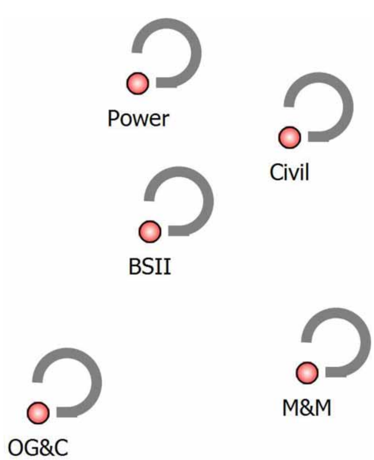

Figure 1 Process improvement CoP by business unit (n_p = 263, n_t = 504)

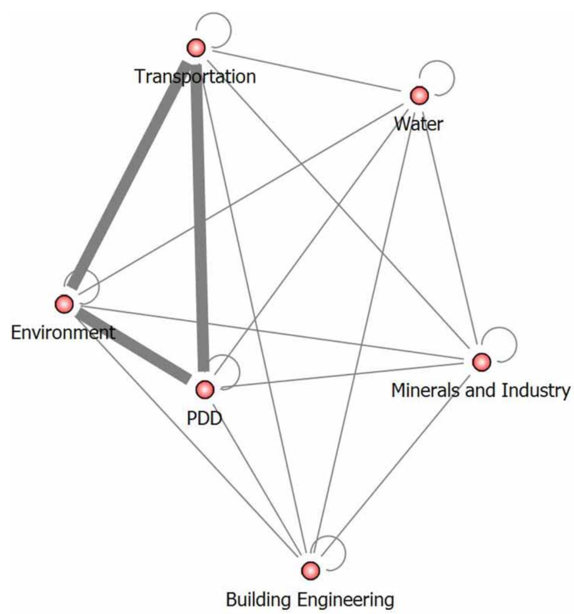

Figure 2 CAD CoP by business unit (n_p = 1045, n_t = 939)

on the HR data sets. We found that there is very little association between business units and disciplinary background. This aligns with qualitative knowledge about the communities. The PI CoP comprises professionals who are selected for the programme from a variety of disciplinary backgrounds, and often placed in different business units post-training. Similarly, the CAD CoP involves professionals who may work across business units to generate drawings, meaning that disciplinary background is not necessarily an important basis for project staffing.

As evidenced by Figures 1–4, there are varying degrees to which informal networks are constrained by formal organizational divisions, although the degree of constraint varies by the attribute considered as well as the community. Using the scale detailed in Table 3, we classified the degree to which each organizational division constrains the informal knowledge-sharing network in Table 4.

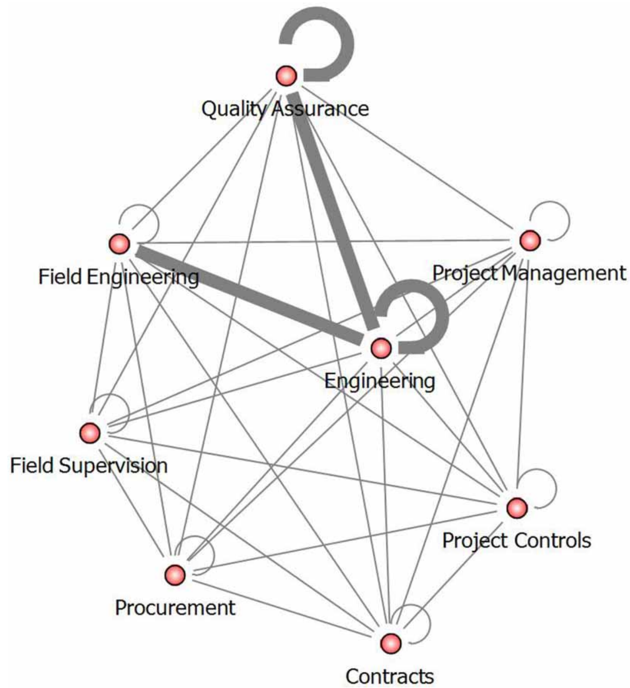

Figure 3 Process improvement CoP by discipline ($n_p = 228$, $n_t = 386$)

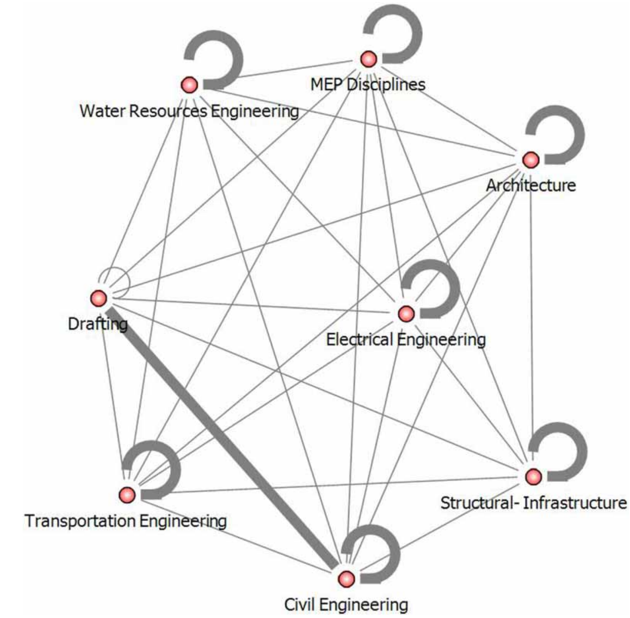

Figure 4 CAD CoP by discipline ($n_p = 402$, $n_t = 394$)

To start interpreting the results, the Process Improvement CoP shown according to business units in Figure 1 offers a clear example of silos. This visualization shows that the network has an extremely limited number of channels through which to share knowledge between business units, and that the informal knowledge-sharing networks are completely constrained by business unit boundaries.

This is in contrast to the CAD CoP shown according to business units in Figure 2, which has normal or strong ties between each business units.

The Process Improvement CoP is shown according to disciplines in Figure 3, which has normal levels of internal ties for most groups, with connections with normal levels of connection between all groups.

Looking at disciplinary groups, the CAD CoP shown according to disciplines in Figure 4 shows a strong tendency to share knowledge within disciplinary groups, but still has connections between all groups. The results from Figures 1–4 are summarized in Table 4.

From the figures and Table 4, there are a number of observations that clearly advance our understanding of knowledge flows in multinational construction and engineering organizations. For Figure 1, there are obvious silos according to Business Units, but for Figures 2–4, it is less clear whether or not this constitutes a 'silo-ed' organization. In Figure 4, there is more connectivity within disciplinary groups than between them; the network has some capacity to share knowledge between these groups. This leads to our first major observation: formal organizational structures do not produce dichotomous outcomes in which

Table 4 Summary of classifications for each CoP

CoP	Division	Figure	Classification
Process Improvement	Business Unit	1	*Complete constraint*; No between-group ties, all groups display strong preference for sharing knowledge internally
	Discipline	3	*Weak constraint*; Some groups have strong internal ties, displaying a preference for sharing knowledge internally, but the majority of groups have normal levels of internal ties, *and connections exist among all groups*
CAD	Business Unit	2	*No constraint*; Normal or strong ties exist among all groups, there is no perceived preference to share knowledge within any group
	Discipline	4	*Strong constraint*; Most groups exhibit a preference to share knowledge internally, but between-group ties still exist

knowledge sharing is siloed or not. Rather, silos must be evaluated in terms of the degree of constraint, which is a continuum.

Analysing the remainder of the data, we observe that no single division produces the same degree of constraint in both communities. In Figures 1 and 2, we see that there is complete constraint according to business units in the PI CoP, but no constraint by Business Units in the CAD CoP. In Figures 3 and 4, we observe weak constraint by disciplines in the PI CoP, but strong constraint according to the same partition in the CAD Cop. This leads to our second major observation: organizational divisions do not produce consistent effects across communities on informal knowledge-sharing networks. The implications of these observations are discussed in the following section.

Discussion

As multinational construction and engineering organizations try to benefit from their global expertise through CoPs, it is vital to recognize and remedy silos that impede knowledge flows. In the prior section, this study produced two observations: first, that silos within multinational CoPs often follow the boundaries defined by business units and functional disciplines, but there, the strength of their effect can vary from group to group within the community. Second, we observed that in different contexts, silos do not consistently form along the same organizational boundary. This means that business units and functional disciplines are not inherently limiting structures. Each of these observations is discussed below.

Evaluating CoPs: the strength of a silo

The results of this study clearly show that organizational structures can constrain informal knowledge-sharing networks, but that the degree of constraint varies depending on the community and the structure considered. Thus, there is a possibility that these CoPs are not functioning as cohesive communities, and that fragmentation can occur along many different dimensions. This leads to the following proposition: *fragmentation in CoPs is a continuous, rather than dichotomous concept and can be evaluated in terms of the proportion of groups that are siloed.*

To dig in to this proposition, the degree of constraint does not indicate absolute numbers of connections, but rather the balance of connections based on the size of groups, and connection density of the network. For instance, weak constraint indicates that there is a normal balance of within- and between-group connections for the majority of groups, while strong constraint would indicate that the majority of groups favour connections between people in the same business unit or discipline. The result is that strongly constrained networks have many isolated groups.

For CoPs, it is very important to determine if there is an imbalance in network capacity by group, because it determines how we evaluate the 'community' element of CoPs. Wenger *et al.* (2002, p. 34) make the case that:

> A community of practice is not just a Website, a database, or a collection of best practices. It is a group of people who interact, learn together, build relationships, and in the process develop a sense of belonging and mutual commitment

To the degree that groups are siloed within the boundaries of a CoP, we must re-evaluate whether the CoP can be classified as a 'community'. When silos do exist along epistemological boundaries like business units (industry-specific knowledge) and disciplines (field-specific knowledge), then the prescribed boundaries of the CoP do not describe the true patterns of interaction. This could be because cross-business unit or cross-discipline knowledge sharing is not useful, indicating that there is no practical value to facilitating knowledge sharing. This conclusion would be consistent with other work that emphasizes the practice-based nature of learning and knowledge sharing in project-based organizations. By this view, professionals enact knowledge within project environments, and the lack of overlap in practice between business units or disciplines may be the true reason for a lack of interaction (Hartmann and Doree, 2015). On the other hand, it could be because there is no adequate facilitation of connection between groups within the CoP. When this occurs, there may be groups of practitioners who *would* benefit from interacting with one another, but have thus far not had the opportunity.

Through viewing CoP cohesion as a continuous measure comprising the proportion of siloed groups, it is possible to evaluate the health of large, multi-lateral CoPs with respect to formal organizational boundaries, and to specifically target areas of the network that are irrelevant to the broader group or under-performing. In the Process Improvement CoP, there are very few connections between business units relative to the size and density of the network. Because of the common process improvement training among these professionals, we conclude that silos exist due to a lack of connection opportunity. If this is the case, then a lack of interaction can be remedied through relatively simple strategies such as networking events, job rotations, and mutual tasks.

In the CAD CoP, however, there is some connectivity between disciplinary groups, although there is a distinct preference for within-group knowledge sharing. This is not sufficient evidence, however, to claim that the CAD CoP is siloed to the point of damaging knowledge flows. Even though there is an imbalance of network capacity to distribute knowledge within groups (many connections) as opposed to between them (far fewer connections), it is difficult to say whether the few connections which span disciplinary groups are sufficient to create a cohesive community, or if the CoP is too broad, and does not reflect job roles and practices.

In any case, group-level evaluation allows us to get at the root issue. If there is relatively little interaction between formalized groups, then it is important to determine if the lack of interaction is due to a practice boundary, or to an interaction opportunity boundary. In one case, the CoP boundary delineates a phantom community, bringing together multiple, unrelated groups of practitioners. If the network is only weakly constrained, it may indicate that there are one or two epistemological groups that do not belong to the knowledge-sharing CoP. When this is the case, removing those groups into a separate CoP may be the most beneficial management strategy. If, however, we are witnessing the influence of an organizational boundary on a CoP that otherwise has a cohesive knowledge domain and practice, then the group should be considered a CoP with unrealized potential. In both cases, fragmentation can occur on a group level, and should be evaluated on a group level.

Lastly, we would like to touch on the role of boundary spanning within CoPs. Even in strongly constrained networks, there are connections that defy the trends of the majority and link different groups. Practically speaking, these boundary-spanning connections can be a powerful change agent for group-level fragmentation, and should be identified and exploited by managers. They represent existing channels of communication between organizational groups which do not require the relational start-up of initiating new connections. Furthermore, boundary-spanning connections can give managers a template for successful knowledge sharing across boundaries in the event that they want to expand the inter-group knowledge-sharing capacity of the network. On a theoretical level, the presence of boundary-spanning connections in the midst of highly constrained networks raises a number of interesting questions such as: How did these connections form? What purpose do they serve in the network? What capacities do boundary-spanning connections have to distribute knowledge throughout the network? Although several studies have broached this topic for small teams (Di Marco *et al.*, 2010; Di Marco and Taylor, 2011), examining the role of boundary spanners in diverse, multinational organizational settings is a ripe area for future research.

Contextual differences

One of the most interesting findings of this study is that business units and functional disciplines did not exhibit the same degree of constraint across both communities. Going back to Table 3, we see that business units completely constrain the Process Improvement CoP, but only weakly constrain the CAD CoP, and functional disciplines weakly constrain the Process improvement CoP, and strongly constrain the CAD CoP. From this, we conclude that knowledge-based organizational structures do not have inherent characteristics that limit connection between groups. Instead, the patterns of interaction that we observe fit more closely with the findings of Hartmann and Doree (2015), in which project-based interactions tend to determine which organizational divisions constrain knowledge-sharing networks. This leads to our second proposition: *Within organizations, commonalities according to business units and disciplines cannot be used to predict the formation of silos*.

First, let us note that grouping people into CoPs by a common interest does not guarantee an overlap in practice. If a CoP is siloed, as is the case with the PI CoP by business unit, it may indicate that there are *practice boundaries* along business unit lines. If this is the case, then it would not be useful for professionals to interact across business units, because the group lacks a cohesive knowledge domain, and a particular practice that is agreed upon (Wenger *et al.*, 2002). Furthermore, this is often reinforced by the project-driven nature of the business, in which CoPs connect professionals who then enact their knowledge while working on project-based problems (Hartmann and Doree, 2015). On the other hand, low levels of interaction do not necessarily indicate a practice boundary. When managers prescribe CoP boundaries, they may include employees who have a cohesive knowledge domain and practice, but have not been connected to one another, and thus do not have community.

Although it is not a part of the formal methodology, the authors have conducted exploratory interviews with members of the Process Improvement and CAD CoPs to try to explain the different patterns observed. Through discussions with CoP participants and leaders, we determined the basic management structure, purpose, and culture of these knowledge-sharing communities to assess why business units so strongly constrain the Process Improvement CoP, and functional disciplines have such a strong effect in the CAD CoP. Through these talks, we learned that Company A, which houses the Process Improvement CoP, encourages competition between the business units, and runs each of these divisions as separate profit centres. Because of this, each business unit develops unique processes and languages that have limited transferability between business unit contexts. Thus, management has fabricated practice-based boundaries that make it difficult to engage in project work across business unit boundaries. Interestingly, one of the goals of the Process Improvement CoP is to facilitate inter-unit knowledge exchange, although based on our analysis, this does not occur. As one interviewee stated:

> Our entire company is organized around these business lines; how each business line executes work is typically dictated by the type of clients within that business line etc. So they have a management style and an execution culture. And so we align all of our different functions within that business unit when in essence in our company the business unit is the ranking entity for work execution. (Manager, Process Improvement CoP)

In contrast, Company B is not rigidly organized into business units, but has grown aggressively through acquiring smaller companies. The CoP provides a platform to encourage knowledge sharing across business units and disciplines, but affiliation is stronger with legacy companies than it is with proscribed business units. In contrast to the Process Improvement CoP, the CAD CoP members specialize in certain disciplinary areas such as pipelines or road design. Most of the drawing blocks, CAD standards, and systems that they use are discipline-specific. Therefore, when CAD employees share knowledge, it is frequently discipline-specific, so it appears that employees seek out connections that have similar educational backgrounds. They see people in different fields as having less relevant knowledge to what they do. One employee, when explaining why they did not have a strong knowledge-sharing connection with another said this:

> I think we do completely different lines of work. He's a structural modeler, I do electrical drafting. So we might talk about Revit, but we wouldn't talk about the finer details of what we do. (CAD Drafter, CAD CoP)

Many of the connections which span these disciplinary boundaries exist to coordinate between multiple disciplines for a project-based need, not to transfer best practices or solve problems. This is consistent with prior studies, which found that project-based needs were a common driver of boundary-spanning connections (Javernick-Will, 2011; Hartmann and Doree, 2015). Aside from project coordination, cross-disciplinary interactions are typically very general and limited to issues with the software that are general to all types of drawings.

On a theoretical level, the differential constraint exhibited by knowledge-based structures across communities shows that commonality between people does not universally drive connection. Cognitive studies that consider homophily consistently document that demographic and socio-economic similarity tends to breed connection between people (McPherson *et al.*, 2001). Taken in the context of the Process Improvement CoP, however, homophily (as demonstrated by within-group connection) does not occur according disciplinary groups. Similarly, in the CAD CoP, we do not observe behaviour consistent with homophily according business units. So then, even though business units and functional disciplines help to define similarity between people, it is not reasonable to conclude that individual association with these knowledge bases is strong enough to create a cognitive 'love of the same' which will cause organizational silos.

To summarize, the inconsistent effects of organizational divisions across communities means that silos might occur along business unit or disciplinary boundaries, but it is not safe to assume that these divisions inherently bound knowledge flows.

Implications for management

For several decades, CoPs have been marketed as a 'silver bullet' solution to create knowledge sharing across organizational divisions and disciplinary boundaries. Many managers have bought in, and believe that logically grouping people into CoPs will naturally lead to cross-boundary knowledge sharing. This study has shown that using CoPs within an organization does not intrinsically overcome the organizational boundaries that cause silos. Although we have shown that silos still form within multinational CoPs, it should be noted that CoPs continue to be a valuable tool to create cross-boundary knowledge sharing. Other literature clearly documents success stories of CoPs rapidly solving complex technical problems, providing innovative new ideas to an industry, and connecting experts who do not typically work together on projects (Wenger *et al.*, 2002).

The results of this study indicate that strong CoPs do not simply appear because the existing structures of the organization influence opportunities to interact across boundaries. Therefore, to create effective cross--boundary knowledge sharing, managers need to devote additional effort within CoP to create strong networks, foster an environment of trust and collaboration, and to reap the true benefits of CoPs. From our findings, we recommend that managers begin by evaluating the boundaries of the CoP, to determine the degree of fragmentation, and if the boundaries within the CoP are practice- or opportunity-oriented. In many cases, a topical commonality (i.e. the use of CAD) is not enough to indicate potential for useful knowledge sharing. Instead, we must consider that disciplinary differences may mean that there is very little useful knowledge to share. When these practice boundaries occur within existing CoPs, then managers should consider dividing the CoP into multiple, smaller groups. This division will allow experts to more easily find each other when they have a technical problem, and make it easier to set a cohesive direction for the community. If, however, the silos are related to opportunity and not practice, then managers can use work exchanges, conferences, project assignment, conference calls, and any number of other mechanisms to create new opportunities for connection across organizational boundaries.

Limitations and future research

As with any study, there are a number of limitations that must be addressed. First, the generalizability of this study is limited due to the small number of communities included in our sample. For this reason, these findings only apply to CoPs that span more than 3 different disciplines and 3 different business units, and have a membership larger than 150, enough to exceed the capacity of a single individual to have social relationships with all other group members (Dunbar, 1993; Gladwell, 2000). In spite of this, our data set is unusually large relative to other social network data on knowledge sharing, so each community represents a large number of knowledge-sharing connections. Furthermore, we are not making a universal claim about the effects of a given organizational division. Instead, we have discussed the ability of formal organizational divisions to constrain informal knowledge-sharing patterns. The generality of these conclusions makes them conceptually robust despite the small number of cases in this study. Even so, it would be beneficial for the knowledge management literature to generate additional social network data sets that can be compared to formal organizational divisions. This study provided a preliminary look into why silos emerged in informal networks, though this is a topic that requires more rigorous qualitative research methods. This study found that mechanisms of organizational control that group employees into business units and disciplinary groups can impact informal knowledge-sharing networks. Future research could go far beyond interaction patterns, and begin to explore why these patterns have occurred. While business units and functional disciplines are formal, epistemological boundaries that are capable of creating fragmentation across potentially relevant domains of knowledge, there are many other organizational forces that can influence patterns of connection. For instance, there are strong numbers of ties between the Civil Engineering and Drafting groups in Figure 4. Why is there so much knowledge sharing between these groups? Is there a practice boundary around these two disciplines? Explaining this complexity is not possible with quantitative SNA methods. Furthermore, although important, this study did not examine the influence of location of connection opportunity, or the dual influence of business units that may be geographically located. Future research would do well to continue this line of inquiry, exploring how and why informal networks are structurally impacted by the dual influence of physical location and management strategies.

Conclusion

Silos that limit knowledge flows in construction organizations can have widespread impacts on a company's efficiency in using its knowledge resources. Business units that become siloed will fail to learn from other business units, compartmentalizing innovation and best practice within a small fraction of the organization. Isolated disciplinary groups lack the coordination required to offer integrated solutions, leading to repeated mistakes and wasted resources. Although CoPs have been explicitly introduced to facilitate global knowledge sharing and prevent these pitfalls, this study found that knowledge-based silos continue to form within CoPs. Furthermore, these silos corresponded with the boundaries defined by business units and functional groups within the organization.

Assessing the relationship between formal organizational structures and informal knowledge-sharing networks is an important step for theory and practice, yet it remains unaddressed in knowledge management literature. This study empirically examines business units and functional disciplines to determine whether formal organizational structures cause silos in multilateral CoPs. To accomplish this task, we conducted a literature review to examine how these divisions affect knowledge sharing, and then examined patterns of knowledge-sharing connections within and between groups in two multi-lateral CoPs. We created a methodology based on statistical resampling and visualization that allowed us to analyse the underlying patterns of knowledge-sharing connections, and used these data to classify group-level ties relative to a simulated network. As a result of this analysis, we observed that formal structures limit knowledge sharing along a continuum of constraint, which requires group-level analysis to determine where silos actually affect knowledge flows. Second, commonalities according to business units and functional disciplines are not an accurate predictor of knowledge-sharing ties between employees, and that the effects of these divisions vary according to the larger context of the organization.

Disclosure

No potential conflict of interest was reported by the authors.

References

Alavi, M. and Leidner, D.E. (2001) Review: knowledge management and knowledge management systems: conceptual foundations and research issues. *MIS Quarterly*, **25**(1), 107–36.

Alin, P., Taylor, J.E. and Smeds, R. (2011) Knowledge transformation in project networks: a speech act level cross-boundary analysis. *Project Management Journal*, **42** (4), 58–75.

Amin, A. and Roberts, J. (2008) Knowing in action: beyond communities of practice. *Research Policy*, **37**(2), 353–69.

Bechky, B.A. (2003) Sharing meaning across occupational communities: the transformation of understanding on a production floor. *Organization Science*, **14**(3), 312–30.

Boland, R.J. and Tenkasi, R.V. (1995) Perspective making and perspective taking in communities of knowing. *Organization Science*, **6**(4), 350–72.

Borgatti, S.P., Everett, M.G. and Freeman, L.C. (2002) *Ucinet for Windows: Software for Social Network Analysis*, Analytic Technologies, Harvard, MA.

Brown, J.S. and Duguid, P. (1991) Organizational learning and communities-of-practice: toward a unified view of working, learning, and innovation. *Organization Science*, **2** (1), 40–57.

Carlile, P.R. (2002) A pragmatic view of knowledge and boundaries: boundary objects in new product development. *Organization Science*, **13**(4), 442–55.

Carrillo, P. and Chinowsky, P. (2006) Exploiting knowledge management: the engineering and construction perspective. *Journal of Management in Engineering*, **22**(1), 2–10.

Chinowsky, P. and Taylor, J.E. (2012) Networks in engineering: an emerging approach to project organization studies. *Engineering Project Organization Journal*, **2**(1–2), 15–26.

Chinowsky, P.S., Diekmann, J. and O'Brien, J. (2009) Project organizations as social networks. *Journal of Construction Engineering and Management*, **136**(4), 452–8.

Cramton, C.D. (2001) The mutual knowledge problem and its consequences for dispersed collaboration. *Organization Science*, **12**(3), 346–71.

Cross, R. and Cummings, J.N. (2004) Tie and network correlates of individual performance in knowledge-intensive work. *The Academy of Management Journal*, **47**(6), 928–37.

Cummings, J.N. (2004) Work groups, structural diversity, and knowledge sharing in a global organization. *Management Science*, **50**(3), 352–64.

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

Di Marco, M.K., Taylor, J.E. and Alin, P. (2010) Emergence and role of cultural boundary spanners in global engineering project networks. *Journal of Management in Engineering*, **26**(3), 123–32.

Dougherty, D. (1992) Interpretive barriers to successful product innovation in large firms. *Organization Science*, **3** (2), 179–202.

Dunbar, R.I. (1993) Coevolution of neocortical size, group size and language in humans. *Behavioral and Brain Sciences*, **16**(04), 681–94.

Efron, B. and Efron, B. (1982) *The Jackknife, the Bootstrap and other Resampling Plans*, SIAM, Montpelier, VT.

Fong, P., Hills, M. and Hayles, C. (2007) Dynamic knowledge creation through value management teams. *Journal of Management in Engineering*, **23**(1), 40–9.

Gladwell, M. (2000) *The Tipping Point: How Little things can make a Big Difference*. Little, Brown and Company, Boston.

Grant, R.M. (1996) Toward a knowledge-based theory of the firm. *Strategic Management Journal*, **17**, 109–22.

Hargadon, A. and Sutton, R.I. (1997) Technology brokering and innovation in a product development firm. *Administrative Science Quarterly*, **42**(4), 716–49.

Hartmann, A. and Dorée, A. (2015) Learning between projects: more than sending messages in bottles. *International Journal of Project Management*, **33**(2), 341–51.

Javernick-Will, A. (2011) Knowledge-sharing connections across geographical boundaries in global intra-firm networks. *Engineering Project Organization Journal*, **1**(4), 239–53.

Javernick-Will, A. and Hartmann, T. (2011) 3 knowledge management in global environments. *Organization Management in Construction*, **23**, 23–40.

Javernick-Will, A. and Levitt, R.E. (2009) Mobilizing institutional knowledge for international projects. *Journal of Construction Engineering and Management*, **136**(4), 430–41.

Javernick-Will, A.N. and Scott, W.R. (2010) Who needs to know what? Institutional knowledge and global projects. *Journal of Construction Engineering and Management*, **136** (5), 546–57.

Kasper, H., Lehrer, M., Mühlbacher, J. and Müller, B. (2013) On the different 'worlds' of intra-organizational knowledge management: understanding idiosyncratic variation in MNC cross-site knowledge-sharing practices. *International Business Review*, **22**(1), 326–38.

Kimble, C. and Hildreth, P. (2004) Communities of practice: going one step too far?, in *Proceedings 9e colloque de l'AIM*, Evry, France, May 2004.

Kogut, B. and Zander, U. (2003) Knowledge of the firm and the evolutionary theory of the multinational corporation: 2003 decade award winning article. *Journal of International Business Studies*, **34**(6), 516–29.

Lave, J. and Wenger, E. (1991) *Situated Learning: Legitimate Peripheral Participation*, Cambridge university press, New York.

Leonard-Barton, D. (1995) *Wellsprings of Knowledge: Building & Sustaining the Sources of Innovation*, Harvard Business Press, Boston.

Liebeskind, J.P. (1996) Knowledge, strategy, and the theory of the firm. *Strategic Management Journal*, **17**(S2), 93–107.

Lindkvist, L. (2005) Knowledge communities and knowledge collectivities: a typology of knowledge work in groups. *Journal of Management Studies*, **42**(6), 1189–210.

Manville, B. and Foote, N. (1996) Harvest your workers' knowledge. *Datamation-Highlands Ranch*, **42**(13), 78–83.

McPherson, M., Smith-Lovin, L. and Cook, J.M. (2001) Birds of a feather: homophily in social networks. *Annual Review of Sociology*, **27**(1), 415–44.

Moreno, J.L. (1960) *The Sociometry Reader*. Free Press, New York, NY.

Noorderhaven, N. and Harzing, A.-W. (2009) Knowledge-sharing and social interaction within MNEs. *Journal of International Business Studies*, **40**(5), 719–41.

Roberts, J. (2006) Limits to communities of practice. *Journal of Management Studies*, **43**(3), 623–39.

Saint-Onge, H., and Wallace, D. (2012) *Leveraging Communities of Practice for Strategic Advantage*, Routledge, London.

Tatum, C. (1989) Organizing to increase innovation in construction firms. *Journal of Construction Engineering and Management*, **115**(4), 602–17.

Wenger, E., McDermott, R.A. and Snyder, W. (2002) *Cultivating Communities of Practice: A Guide to Managing Knowledge*, Harvard Business Press, Boston, MA.

Wenger, E.C. and Snyder, W.M. (2000) Communities of practice: The organizational frontier. *Harvard Business Review*, **78**(1), 139–46.

White, H.C., Boorman, S.A. and Breiger, R.L. (1976) Social structure from multiple networks. I. Blockmodels of roles and positions. *American Journal of Sociology*, **81** (4), 730–80.

Yuventi, J., Levitt, R. and Robertson, H. (2013) Organizational barriers to productivity and innovation in large-scale, U.S.-based photovoltaic system construction projects. *Journal of Construction Engineering and Management*, **139**(10), 06013003. doi:10.1061/(ASCE)CO.1943-7862.0000767