ALIGNING INNOVATIONS TO NETWORKS: THE GLOBAL CHALLENGE[1]

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Abstract

We analyze the adoption of three comparable technological innovations in computer-aided drafting through networks of firms in the United States and Europe to investigate the impact of market structure on networks and diffusion. We observe that the allocation of work and the role relationships between specialists in the network vary across market structures. We find that (1) innovations that align to the allocation of work in the network diffuse more quickly and (2) role relationships between specialists in the network moderate the impact of misalignment on diffusion.

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1. Introduction

Researchers investigate why some innovations diffuse more quickly than others to both understand and improve market acceptance rates. Research on this point, however, has largely focused on traditional, hierarchical organizations within the context of single countries (Damanpour, 1991; Henderson & Clark, 1990; Tushman & Anderson, 1986; Utterback, 1994; Van de Ven, 1986). In the innovation literature, researchers have called for theories to better understand network forms of organizations (Daft & Lewin, 1993). Meanwhile, researchers of the evolving network form of organization are identifying concomitant issues for learning and innovation (Barley, Freeman & Hybels, 1992; Gann & Salter, 2000; Lampel & Shamsie, 2003; Powell, 1987, 1990, 1998; Powell, Koput & Smith-Doerr, 1996). In this paper we investigate market acceptance of software innovations through networks of firms in the United States and Europe to explore the impact of the network organizational form and national market structure on technology acceptance.

2. Innovation in networks

2.1. The evolution from hierarchy to network forms of organization

Many researchers embrace the shift from hierarchy to network forms of organization as a means for organizations to become more dynamic and flexible (Drucker, 1993), to more effectively distribute costs and risks (Mowery, Oxley & Silverman, 1996), to capture the benefits of information technology (Malone, Yates & Benjamin, 1987), and to achieve transaction cost economies (Williamson, 1975). Others have raised questions about the impact network forms of organizing might have on performance (Powell, 1990). Researchers agree, however, that a proliferation of organizational forms is emerging between arms-length, market-based interactions on one extreme, and hierarchical organization on the other. Some researchers have argued that a theory of post-industrial organizing might appropriately view the firm as context for these project networks (Barley & Kunda, 2001). Though much is known about innovation in markets and hierarchies, little research to date explores the issues associated with innovation in the networks that populate what researchers have coined the “swollen middle” between market and hierarchical forms (Hennart, 1993).

Few industries adopted network organizational forms before the 1990s (Lampel & Shamsie, 2003). Therefore, a useful approach to consider the impact of the network organizational form on innovation is to separately review literature on industries that specialized into networks comparatively earlier from those that adopted network forms more recently. Traditional industries that began organizing into networks around the time of World War II include; aerospace, defense, construction, and film industries. Contemporary industries that evolved into networks of specialists after about 1990 include; biotechnology, pharmaceutical, information technology, and healthcare industries. By contrasting the literatures on traditional and contemporary networked industries we can also observe the effect of time on innovation capacity.

2.1.1. Traditional network industries

Early work on network forms of organizations focused on the construction industry. Stinchcombe (1959) introduced the notion of craft as an alternative to bureaucratic organization based on his investigation of the construction industry. In the same study Stinchcombe found that organizing construction activities under a single hierarchical organizational structure was both expensive and inefficient. In a later study of the residential construction industry in Massachusetts, Eccles (1981) introduced the "quasi-firm" concept. The quasi-firm network was characterized by stable firm relationships over long periods of time between general contractors and subcontractors. Eccles introduces the concept of the quasi-firm as an extension to Williamson's (1975) conceptualization of markets and hierarchies. According to Stinchcombe's and Eccles' arguments, in the building industry there is a clear need to specialize into networks. However, their research was completed relatively early in the transition from hierarchy to networks of specialist organizations. More recent research finds construction networks that evolved over the past 50 years have led to an industry with broken learning and feedback loops (Gann & Salter, 2000) experiencing difficulties for innovation (Tatum, 1989) and with increasing problems adopting system-level, overall productivity-enhancing innovations (Taylor & Levitt, 2004).

Lampel and Shamsie (2003) recently published a retrospective study of how capabilities evolved in the film industry following the move from hierarchical studio organizations to network forms of organization in the 1950s. Their research revealed that when work was organized under the hierarchical studio arrangement, it was more likely to be valued according to its contribution to the firm as a whole. However, when the industry transitioned to network forms of organizing, it was more likely that some capabilities would gain at the expense of others. The research concludes that over time the move from hierarchy to networks of specialists created an "evolutionary stagnation" in the film industry. Faulkner and Anderson (1987) find that, after the movement to network forms of organization in Hollywood, incentives to share knowledge were reduced.

Comparing the traditionally networked construction and film industries, we find a common difficulty in adopting system-level changes. The move from hierarchy to networks enabled these industries to achieve significant economies and flexibility (Eccles, 1981; Stinchcombe, 1959). However, over time, specialists in the network had less incentive to share knowledge and became more focused on their own internal knowledge requirements. Specialists who had worked under the previous hierarchical arrangement in single firms and understood system-level knowledge began to retire in the decades that followed the move to networks.

2.1.2. Contemporary network industries

Since 1990, contemporary industries have begun to adopt network forms of organizing. Powell (1998) studied the pharmaceutical industry's evolution to networks and began to identify difficulties for innovation and learning suggesting it was both difficult and critical to take lessons learned from one project and make them portable across many relationships. In other words, the differing groups of participants from one project collaboration to another make system-wide learning or change difficult. Other work on the pharmaceutical industry (Zeller, 2002) finds Swiss pharmaceutical firms that evolved to networks of specialists observed a decrease in innovation in situations of inter-firm cooperation using project teams.

In the biotechnology industry, Barley, Freeman and Hybels (1992) identified that the use of network forms of organization was growing in comparison to hierarchical, free-standing firms. Zucker, Darby, Brewer and Peng (1996) later found that over time the organizational boundaries separating firms in the network restricted intellectual diffusion. Powell (1998) and Powell, Koput and Smith-Doerr (1996) also investigate biotechnology networks and raise questions as to the ability for firms to sustain system-level learning. Biotech firms that initially entered into alliances with the goal of working together and sharing knowledge were finding it increasingly difficult to do so.

Luke, Begun and Pointer (1989) revisit the quasi-firm concept introduced by Eccles (1981) to investigate the move to networks in the healthcare industry. Their research found that the organizational forms emerging in the healthcare industry resembled those identified by Eccles in construction. In their findings they argue that the quasi-firm concept inadequately captured the inter-organizational arrangements emerging in healthcare. They suggest that more research be undertaken to evaluate quasi-firm performance.

2.1.3. Contrasting traditional and contemporary network industries

The traditional and contemporary evolutions to network forms of organizations are separated by a span of approximately forty years. By contrasting the respective industry literatures across the two industry groupings we can begin to understand the impact of time on innovation and learning in networks. In the traditional network industries, there was a clear breakdown in the networks' ability to adapt to system-level changes over time. This was highlighted by a reduction in the rate of diffusion of system-level innovations and an observed stagnation in the industries' ability to change. In contrast, the contemporary network industries described neither a specific reduction in innovation diffusion rates nor stagnation in the ability to adopt system-level changes. However, in each the pharmaceutical, biotechnology and healthcare industries, there were early indicators that firms in the network alliances were reducing their knowledge exchanges and that the network itself was showing signs of a reduction in its capacity to innovate. This is not surprising since the pharmaceutical, biotechnology and healthcare industries only recently made the transition from hierarchy to networks.

2.2. Innovation background and framework

As outsourcing of specialized skills increases in networks, product and process innovations with the potential to improve overall productivity significantly (e.g., prefabrication of component systems, supply chain integration practices, and integrated software applications) often require multiple interdependent firms to change their processes. Although they hold the promise of significant increases in productivity and profitability, these innovations have difficulty diffusing through network forms of organizations (Taylor & Levitt, 2004). Traditional, hierarchically organized manufacturing industries have adopted similar innovations efficiently and captured significant gains in productivity (Lillrank, 1995). Meta-analyses have shown that the type of organization is the key determinant in interpreting organizational innovation studies (Damanpour, 1991).

Researchers propose that networks be considered as the locus for innovation (Powell, 1998). Others suggest that observing single firms within an innovation study is incomplete (Afuah, 2001). However, most innovation research focuses on firm or industry level innovation processes. Innovation research generally conforms to either firm level (adopter) or market level (macro) studies (Attewell, 1992). Adopter research focuses on the willingness of an individual or firm to adopt an innovation. This literature concerns itself with understanding the innovativeness of individuals and organizations by studying the decision-making processes and innovativeness of the adopter. The decision-making process is broken down into a number of phases: knowledge, persuasion, decision, implementation, and confirmation (Rogers, 1962). Adopters themselves are categorized based on their adopter behavior as innovators, early adopters, early majority, late majority, or laggards (Rogers, 1962). Unlike research oriented toward firm behavior, macro-oriented research focuses at the market level on a population of firms' ability to adopt. This research tends to focus more on the structural characteristics of the adopting population.

In this paper we explore the structural mechanisms impacting diffusion in populations of network forms of organization. We specifically investigate innovations that impact all or some of the specialists in the network. This is a central aspect of our research since the literature on traditional and contemporary networked industries suggests that adopting network forms of organizing may lead to a reduction in the ability to diffuse system-level changes. Researchers have contrasted local and system level innovations as architectural innovations in photolithographic alignment equipment (Henderson & Clark, 1990). Other researchers have investigated the part-whole dichotomy in innovations (Van de Ven, 1986). Still others have explored the impact of technology on the structuration of networks within organizations both conceptually (Giddens, 1979) and through empirical investigations (Barley, 1990). Finally, other researchers have identified difficulties for system-level learning and innovation in loosely coupled networks (Weick, 1976). For the purposes of this paper we adopt the architectural innovation framework introduced by Henderson and Clark (1990).

3. Design and methods

In this paper we explore the impact of the network form of organization on the diffusion of architectural innovations. Roles and role relations in networks can be influenced significantly by the variety of national capitalism (Hall & Soskice, 2001), the level of economic development

(Lucke, 1993), technological style (Hughes, 1983), system embeddedness of knowledge (Birkinshaw, Nobel & Ridderstrale, 2002), and knowledge sharing tendencies (Appleyard, 1996). Therefore, we elected to study networks in both the United States and several European countries to highlight any similarities or and differences that may emerge from our data.

3.1. Research design

3.1.1. Construction industry network focus

Our review of the literature on traditional and contemporary industries adopting network organizational arrangements suggests that the effects on system-level innovation amplify over time. Therefore, we selected the traditional network industry of construction on which to focus our data collection effort. This decision was buttressed by the fact that researchers typically point to construction as exemplifying the network form of organization (Powell, 1987, 1990). Furthermore, the construction industry has been the focal point of numerous studies that have advanced our understanding of organizations introducing the concepts of “craft” administration (Stinchcombe, 1959), contracts as hierarchy (Stinchcombe, 1985), and the earliest discussions of the network form in Eccles’ (1981) study of the “quasi-firm.” The construction industry is also the largest contributor to gross domestic product in most developed countries in the world.

Pettigrew (1990) suggests research designs employ polar cases so that comparisons can be transparently observable. In the Hall and Soskice (2001) work on varieties of capitalism, Finland was identified as a coordinated market economy (e.g., particularistic, with long term relationships) and the United States as a liberal market economy (e.g., universalistic, arms-length relationships, and one-off contracting). This is important to consider if we are comparing networks in different countries as role relationships might be significantly impacted by these differences. Consequently, we chose to concentrate our data collection efforts on construction industry networks in the United States and Finland (though some important, anecdotal evidence is included in studies from France and Germany) on the basis that they provided “polar” contrasting cases. Based on Yin (1989) we selected the networks for our research design in order to support analytic generalization. Because we expect the findings to vary across these two case networks, we apply theoretic replication logic (Yin, 1989).

In most cases, the networks we researched consisted of an owner, an architect, an engineer, a general contractor, numerous subcontractors (e.g., plumbing, HVAC, electrical, framing), and fabricators (see Figure 1). We define the network as the group of specialist firms contracted to work together on specific construction projects. We view projects as instances of work for the network. Examples of projects in the context of this paper include the design and construction of a building, the fabrication of a section of a building, or the construction of a home.

Insert Figure 1 about here

3.1.2. Building information modeling innovations studied

We identified three comparable technological innovations in the construction industry on which to focus our data collection. Software vendors in the industry recently introduced an object-based modeling version of computer-aided drafting (CAD) software that enables architects, engineers, contractors, subcontractors, and fabricators to build three-dimensional computational models of building components with intelligent objects. This new functionality is described in the industry as virtual design and construction, model-based design, and building information modeling. We will refer to this new generation of CAD software as building information modeling software. In the 1980s, early CAD software enabled the digital representation of a building through two-dimensional line drawings on personal computers. By the 1990s, some vendors began introducing CAD software packages that allowed for sophisticated design and representation of three-dimensional geometries. Only recently, however, have mainstream CAD software vendors begun marketing object-oriented building information modeling systems.

The evolution from paper-based drafting to two-dimensional, line-based CAD required a change in work practice within the organization. Different firms in the network could adopt this practice within their firm's boundaries without changing interdependencies with other specialists in the network. Firms continued to exchange sets of plans as blueprints. This meant early adopters of CAD tools could still interact in much the same way with others who still produced drawings manually. The evolution from two-dimensional line-based CAD to three-dimensional CAD geometries had a similarly localized effect. Exchange of documents remained for the most part paper-based blueprints. The three-dimensional views were used primarily by architects to better illustrate designs to owners and were not exchanged electronically with other specialists in the construction network.

The more recent evolution from three-dimensional CAD geometries to three-dimensional building information models creates new interdependencies and collaboration requirements for firms in the construction network without greatly altering the end product (e.g., a set of blueprints). Therefore, we chose to focus on the move to building information modeling as an architectural (i.e., system-level) innovation in the construction industry network in this paper.

To capture any effects across countries we selected innovations which originated in the United States and Europe. Each of the building information modeling vendors included in the study had sales in both the United States and in Europe.

In our study, we focus on three specific building information modeling applications. Since we used theoretic replication logic in the selection of “polar” networks, we opted to use literal replication logic in the selection of three similar innovations (Yin, 1989). Our expectation was that the findings for the three building information modeling applications would not vary significantly. This enabled us to focus on the variances introduced by varying the market structure while maintaining consistency across the technologies introduced. By incorporating literal and theoretic replication logic strategies in our research design, we increase the external validity of our findings.

The first innovation we studied, which we call Building Modeler, was developed by a global software firm based in the United States with sales and development offices in Europe. They focus their marketing and development efforts largely on the needs of architects. The second building information modeling application in our study, which we call Structural Modeler, is produced by a global software development firm based in Finland that focuses their product development and marketing on structural engineers. They also have offices in the United States. We call the third application included in our study the Home Modeler. The company that created Home Modeler operates in the United States through a subsidiary but is based in Finland. Their building information modeling application targets the homebuilding market.

3.2. Data collection and analysis

Researchers suggest that grounded theory building research include multiple case studies (Eisenhardt, 1991) and multiple data collection methods (Eisenhardt, 1989) in order to increase the validity of the constructs identified. In this paper we investigate three architectural innovation cases diffusing through construction networks in the United States and Europe. We employ multiple data collection methods; including, ethnographic interviews, direct observation, and review of primary and secondary documentation. By triangulating our findings across these different data collection methods we hope to strengthen the validity of our findings (Eisenhardt, 1989).

The data collection effort for this paper took place from spring 2004 through winter 2005. Three months were spent based in Finland collecting data in Europe from summer 2004 through autumn 2004. We conducted multiple interviews with employees from the three building information modeling application vendors included in the study and collected primary documentation from each. However, the bulk of our data was collected from the United States and Finnish construction networks included in our study. We conducted over 200 hours of interviews in 82 discussions with owners, architects, engineers, general contractors, subcontractors and fabricators. Of the interview discussions, 31 were with construction network specialist firms in Finland and the remaining 51 were within the United States. In most cases we interviewed the individual in the organization most involved in managing the company's utilization of CAD products. This individual was typically referred to as the "CAD Manager" or the "CAD Director." In some instances we spoke to more senior managers. In all cases we focused the interview discussion on specific project experiences where transitions to building information modeling CAD applications occurred.

In addition to interview discussions, direct observations were made within specialist firms to observe the process of building information modeling. We were invited to attend company meetings and project discussions, to visit project sites both under construction and recently completed, and to generally observe the interaction between specialists in the network. We took extensive notes during this process and took digital photographs for use in our data analysis. Interview discussions and observations were recorded in a numbered set of field research notebooks. Interview discussions were also recorded using a digital voice recorder.

Whenever possible, we requested hard copies of materials discussed during interview discussions and observations. Data collected included contract documents, process flow diagrams, construction schedules, building information models, bills of materials, project decision schedules, animations of building information models, and any other information that might lend insight into the internal and inter-organizational practices of the network in adopting building information modeling applications. This primary documentation was attached to our field notebooks and often elucidated concepts that were not entirely clear when reviewing the notes from an interview or observation. We also obtained temporary licenses for the building information modeling software from one of the three vendors included in the study. This allowed us to develop a familiarization with the technologies being adopted by the United States and Finnish construction networks that we observed in the course of this research.

The research project also benefited from many informal discussions with informants who had an overall perspective of the use of CAD in both the United States and Finnish construction networks. We were able to attend a conference related to building information modeling applications both in the United States and in Finland and were able to speak to many users. In the interactions with the informants and the conference users, were able to review our findings and thereby further increase the validity of our constructs. Overall, we were able to manage the reliability of our findings by keeping an indexed, organized database of our field notebooks, audio interview files, photographs, and documents collected.

The data collected in this project were entered into a qualitative data analysis software package. Data from the interviews, observation, documentation, and photographs were coded and systematically analyzed for patterns. Memo notations were used to develop concepts and constructs. Constructs were grouped into propositions that could contribute to an explanation for market acceptance of architectural innovations in networks of specialists. Propositions were analyzed and grouped together to build grounded theory from the data collected.

4. Network, innovation and market structure findings

We designed this research and data collection effort to compare innovation acceptance across firm networks within different countries. The purpose was to gain insight into how architectural innovations diffuse through networks of firms. In the past, researchers of architectural innovations focused primarily on cases where the architectural change was encapsulated within a firm's boundaries (Henderson & Clark, 1990). However, researchers observing architectural innovation acceptance across firm boundaries (Afuah, 2001) found that organizational boundaries made adapting to architectural change and developing appropriate transition strategies difficult. Afuah (2001) concludes that innovation studies that only include focal firms are incomplete. In our research we found that the key to understanding architectural innovation across firm boundaries lay in a finer-grained understanding of how work is allocated in networks and of role relations between specialists in the network.

4.1. Allocation of work to specialists in networks

During our data collection effort in Finland, we were surprised to learn that work in the construction network is allocated in a fundamentally different way from networks in the United States. In one interview we sought to understand how the firms in one Finnish network used the Home Modeler building information modeling application. We were specifically trying to understand whether or not the architect did the final detailing of the design or whether it was handled by the contractor, subcontractor or fabricator. However, we were having a great deal of difficulty getting the interviewee to understand the concept of "detailing."

To resolve the situation, the interviewee firm invited a professional translator into the meeting. After some deliberation, the translator suggested that the problem in communication was due to the fact that a single verb, *suunnitella*, describes both the designing and detailing process in the Finnish language. Furthermore, there is no separate verb to describe the act of designing or detailing. In Finnish work practices, the designer always does the detailing work. Therefore, the architect using the Home Modeler application both designs and details the model.

In contrast, work allocation in construction networks in the United States using the Home Modeler application is quite different. In the United States, the architect is only expected to provide a schematic design of the home. The downstream partners in the network detail the design provided by the architect. One architecture firm in the United States describes architectural designs as follows:

> "Design professionals don't use exact dimensions. Contractors interpret these (*refers to the architect's drawings*) and create shop drawings with actual dimensions … if a dimension is wrong, it's the contractor's fault."

To confirm the generality of this work allocation practice, we posed similar questions to construction networks in Finland and the United States implementing the Building Modeler and Structural Modeler applications. The work practice of architects providing schematic designs in the United States and "detailed" designs in Finland was also true for the networks using the Building Modeler application. However, we were surprised to learn that users of the Structural Modeler application could be observed to allocate work in similar ways even though no architect was involved. A Finnish structural engineer described the process in Finland in this way:

> "The structural engineer is responsible for the structural analysis (*draws a process flow diagram*) which is an iterative process of assuming member sizing, applying loads, checking deformations, stresses and support reactions. You check the codes and if everything is okay you do all the connection details, slot holes, connectors..."

In contrast, fabricators complete the final detailing of schematic designs provided by structural engineers in the United States. They are then able to adjust the connection details to match their operations and available inventory. For example, a design may require a certain member sizing and connection detail, but in order to save time and costs in the fabrication process, the fabricator might suggest using a slightly larger member and bolt size to divest themselves of inventory surpluses. In the Finnish construction networks, this practice is much less likely since fabricators fabricate structural materials to the exact, detailed specification of the engineer.

Our finding of how work is allocated to specialists was consistent within each national market structure and across the three innovations included in the study. Given this commonality, we consider the finding that work is consistently allocated differently –designers complete “detailing” work in Finland but not in the United States– across markets to be significant. Though significant in this study, the idea of different countries having different approaches to technology and work is not new. Hughes (1983) published a comprehensive study of how differing technological styles produced significantly distinct electrification systems in different countries. We will discuss the implications of this finding to the research questions investigated in this paper in a later section.

4.2. Variety in network role relationships

In Eccles’ (1981) study of the construction industry, he identified that construction firms operated in networks with long-term relationships and only contracted with one to two specialists of each type. These longer term relationships were not based on having the lowest price. Interestingly, in our study, we found that Finnish construction networks contract more along the lines described by Eccles with firms engaging in tight partnership relationships with one to two firms for each specialist type in the network. In contrast, construction networks in the United States tended to adopt shorter term relationships than those identified in Eccles’ study. United States construction firm networks disclosed that a reasonably small number of firms with which to contract for each specialist type would be five to six different firms. Many firms cited cost pressure as a rationale for adopting a more arms-length approach to contracting. In the 25 years since the Eccles’ investigation of the quasi-firm, the construction network has evolved to shorter-term relationships with more firms in the United States. We describe the variety in the firms that are contracted for each specialist role in the network as *organizational variety*.

Organizational variety is a key construct for understanding market acceptance of architectural innovations. However, we identified several other inter-related sub-constructs that determine the magnitude of the impact of *organizational variety* on market acceptance. The first of these constructs is *degree of interdependence*. The *degree of interdependence* did not appear to vary in Finnish and United States construction networks. In both cases the *degree of interdependence* was high (reciprocally interdependent). Thompson (1967) introduces the concept of classifying interdependence into the literature describing sequential, pooled and reciprocal interdependence. Thompson introduced the concepts to illustrate how interdependence influences organizational structure. The least interdependent form was termed "pooled" interdependence to describe activities where work does not flow between units. "Sequentially" interdependent activities were defined as those where the output of one group is the input of another. "Reciprocal" interdependence was the most interdependent classification. It described work where the output of two groups must be negotiated to address sub-goal conflict.

A second sub-construct identified relating to *organizational variety* in construction networks was *organizational boundaries*. *Organizational boundaries* between firms in a network were comparatively rigid in United States. These *organizational boundaries* were constrained by contractual agreements and work standards. However, in Finnish construction networks, firm boundaries were more fluid and supportive of changes entailed with architectural innovations. For example, in the adoption of the Building Modeler application in the United States, several firms vertically integrated into a single firm when attempts at partnering and alliances were unsuccessful. In contrast, in Finland firms adopting the Home Modeler application redrew the organizational boundaries separating the firms in the network without losing their firm identity.

Another sub-construct identified as relating to the *organizational variety* construct was *interests*. In the United States, firms in construction networks were focused on the *interests* of their own firm. In one illustrative case, an architecture firm in the United States opted not to inform their customers or network partners that they were using the Building Modeler application even though sharing such information and files would greatly reduce downstream work and errors. They stated clearly that they wanted the benefits of the new technology to accrue only within their own firm. In the Finnish case, firms were much more apt to share the benefits of building information modeling with their network partners. In the case of the Structural Modeler application, structural designers in construction networks in Finland chose to share models with downstream fabricators to obviate the fabricator's need to produce their own electronic CAD files for manufacturing.

A fourth sub-construct identified in comparing Finnish and United States construction networks was the presence of an *agent for system-level change*. In the United States, the networks are self-organizing in the face of system-level change. Since the knowledge of architectural change is distributed across multiple firms in networks, rational self-organization among firms in the network may not lead to the most rational solution for the entire network. Van de Ven (1986) argues that in instances such as this, impeccable micro-logic can lead to macro-nonsense. In contrast, in Finland the national funding agency promotes system-level productivity enhancing changes by subsidizing the costs such a change may have on individual firms in the network. In doing so, the national funding agency fulfills the role of agent for system-level change.

The final sub-construct we identified in our research in comparing Finnish and United States construction networks was *industry fragmentation*. The United States construction industry is populated with many, small firms operating in numerous construction networks. The Finnish industry is populated with few, large firms that work together in a smaller number of construction networks. As one Finnish contractor commented, "we all know each other, we go for beers at the same pubs, we visit the same saunas." We summarize the constructs and sub-constructs identified in comparing United States and Finnish construction networks in Table 1.

Insert Table 1 about here

4.3. Network and innovation alignment

4.3.1. Building modeler

The Building Modeler application replaced existing technologies for conceptual architectural design and detailing into an integrated building information modeling package. In Finland where construction networks allocated design and detailing work to designers, this integrated technology was able to diffuse much more quickly than in the United States. An interviewee from the firm that created the Building Modeler application described the situation as follows:

> "Internationally, acceptance of our products seems to have a lot to do with process. In Europe firms are more model-oriented. Back home in the U.S., firms are much more geared toward drafting."

A Finnish architectural firm adopting the Building Modeler application could do so without changing the work completed by different specialists in the network. The model-based approach of building information modeling provided architecture firms in Finland with a single software application that reduced gaps, overlaps, and issues of file exchange between disparate applications within their firm. In the United States, however, the detailing of designs is done by another specialist in the network other than the architect. Adopting the Building Modeler application meant either that architects would need to specify buildings in more detail or that downstream specialists in the network would need to adopt and use a similar modeling application. Since architect fees do not include the detailing work and architects are not trained to provide detailed designs, architecture firms in the United States were slow to adopt Building Modeler. In the work allocation of United States construction networks, downstream specialists could gain value from the Building Modeler application, but since it only impacted a portion of the work allocated to them they also were hesitant to adopt.

Comparing market acceptance for the Building Modeler application in the United States and Finland we observe a distinct difference. The Building Modeler innovation *aligned* with the existing allocation of work to specialists in the construction network. The Building Modeler innovation integrated and improved work already being completed by Finnish architecture firms. In contrast, the Building Modeler innovation was *misaligned* with the allocation of work to specialists in the United States. The application provided more functionality than was required by the architects and insufficient functionality for downstream network partners.

Construction networks in the United States that did adopt the Building Modeler experienced difficulties because the *organizational variety* in the network was high. Construction networks in the United States experience significant variability in the mix of specialist firms contracted for any given project. Since the Building Modeler application required firm networks to change the allocation of work and shifted interdependencies, the *organizational variety* of network participants exacerbated problems associated with implementing the application in the network. Figure 2 illustrates the *alignment* of the Building Modeler application with the existing allocation of work to specialists in United States and Finnish construction networks and points out the impact of *organizational variety* on market acceptance in each case.

Insert Figure 2 about here

Because *organizational boundaries* in the United States construction networks were rigid, several firm networks in our study vertically integrated to accommodate the technological change. These integrated networks described *interests* as a key motivator for adopting a strategy of integration. Firms in the network expected other firms in the network to use the change in work allocations as a way of increasing their firm's revenues and improving their profit margins. Because of the *industry fragmentation* and the lack of an *agent for system-level change* firms in the network were forced to self-organize into cooperative networks. Most of the firms in our study found this too difficult to accomplish compared to the expected gains from the Building Modeler application. Those networks that vertically integrated forming hierarchically organized firms, in effect, *aligned* themselves to the system level change introduced by the building information modeling architectural innovation.

4.3.2. Structural modeler

The Structural Modeler application substantially integrated the design, detailing, and fabrication of structural materials in construction networks. The level of integration in the construction network required by this innovation meant that there would be some *misalignment* to both the United States and Finnish construction networks. The allocation of work to specialists in the network illustrates (in Figure 2) that in the United States the *misalignment* occurs at the interface between design and detailing. In Finland, the *misalignment* is at the interface between detailing and fabrication. Because construction networks in both countries contain *misalignment* between the innovation and the allocation of work in the network, the case of the Structural Modeler is particularly useful for observing the impact of the *organizational variety* construct and related sub-constructs.

An interviewee from the firm that created the Structural Modeler application gave some illustrative quantitative figures for market acceptance of their product in the United States, Finland, France and Germany. The product, which was created in Finland, achieved a nearly 100% market penetration in Finland over the period from the product launch in 1994 through 2004. In comparison, in France and Germany (which adopt comparable strategies to Finnish networks for allocation of work) the Structural Modeler application achieved a 60%-70% market penetration in the period from 1996 to 2004. This diffusion rate is roughly comparable to the market acceptance in Finland. In sharp contrast, market acceptance for the Structural Modeler application was much slower in the United States. In the period from 1997 to 2004 they had only managed to achieve a 20%-30% market penetration in the United States even in the relative absence of competing products.

An exploration of the *organizational variety* construct and related sub-constructs provides some explanation for why construction networks in Finland, Germany and France were able to adopt the Structural Modeler application more quickly than United States construction networks. The European construction networks tended to have longer-term relationships with fewer fabricators. Therefore, the *organizational variety* in the network was low. This was partly due to the fact that networks were formed from industries with fewer, larger firms (*industry fragmentation*). When work allocation and interdependencies shifted in the face of the new technology, *organizational boundaries* between firms in the network were fluid enough to accept the change and *interests* were aligned to the network therefore individual firms did not use the change as an opportunity to game on price. Finally, in each of the three European countries where market acceptance was swift, national agencies existed to act as *agents for system-level changes* that were required by Structural Modeler. Overall, the *organizational variety* and related sub-constructs enabled Finnish, German and French construction networks to adapt to the system-level technological change introduced by the Structural Modeler application.

In United States, construction network work allocation was also not *aligned* to the Structural Modeler innovation. In the United States network case, the *misalignment* occurred at the interface between the design and detailing work which was completed separately by structural designers and fabricators but integrated in the Structural Modeler application. The high *organizational variety* in United States construction networks exacerbated the impact of this *misalignment*. Since firm *boundaries* in the network were rigid, it was difficult to shift work allocations and interdependencies. In cases where firms tried to reduce the *organizational variety* in their network, they ran into issues of structural design firms being unwilling to share building information models with downstream fabricators (due to a focus on firm vs. network *interests*). Because no *agent for system level change* existed, firms were forced to self-organize around the change. Redistribution of risks and rewards and a focus on firm-level *interests* meant that networks faced difficulty self-organizing around the technological change. In the case of United States construction networks, the acceptance of the Structural Modeler innovation was exacerbated by high *organizational variety*.

4.3.3. Home modeler

The Home Modeler building information modeling application integrated the technologies involved in design, detailing and fabrication for home construction. Limited market data was available for the United States since the firm had only recently begun marketing the Home Modeler application in the United States. However, evidence from Finland clearly pointed to rapid market acceptance of the Home Modeler innovation even though there was a structural *misalignment* between the detailing and fabrication work allocation in the network. One network included in the study provides a case for understanding the *organizational variety* in the Finnish construction network. This firm grew from a market share of about 1.5% in 1990 to over 18% in 2004. They attribute much of this growth to the tight partnerships developed and nurtured within their network. In the face of technological changes like the Home Modeler application they described getting all the firms in the network together to discuss how they could successfully implement the technology (implying fluid *organizational boundaries*) and how risks and rewards would be distributed in the network (implying network sharing *interests*). They described the role of the national funding agency in subsidizing the costs of early implementation for system-level changes in the network (implying an *agent for system-level change*). They did not mention *industry fragmentation* as a concern. Overall, they were able to mitigate the *misalignment* of the allocation of work in the network and the architectural innovation through low *organizational* *variety*, fluid *organizational boundaries* in the network, a network appreciation of *interests*, and the presence of an *agent for system-level change*.

5. Conclusions

The findings from the three innovations in building information modeling show that an *alignment* of innovations to networks greatly increases the rate of market acceptance for architectural innovations. Data from construction networks in Finland, Germany, France, and the United States show that in cases of *misalignment* of innovations and the allocation of work in networks, the *organizational variety* in the network can act to either mitigate or exacerbate the impact of the *misalignment*. This research contributes to our understanding of the role of firm boundaries and the allocation of work within networks on the market acceptance of architectural innovations. Previous research on architectural innovations has focused primarily on within firm architectural changes. This research suggests that organizational and work allocation boundaries are critical to understanding the market acceptance of architectural innovations.

This research contains limitations that should be addressed in future research on the subject of innovation in networks. The findings are based on a limited set of cases and, therefore, though validity and reliability of the qualitative data were managed in the research design, further research should be undertaken to gather quantitative data in support of these claims. We attempted to access formal diffusion data for the different building information modeling applications included in this study. However, we were unable to gain access to this data and this therefore represents a further limitation for this research. Future researchers should study quantitative diffusion data to both refine our understanding of the impact of *alignment* of innovation and networks on diffusion and to measure the impact of *organizational variety* on market acceptance in cases of *misalignment* of innovations and networks.

Several construction networks in the United States overcame the impact of high organizational variety through strategies of vertical integration. A promising direction for future research would be to investigate whether a contingency theory applies to organizational networks. This could usefully be explored through both qualitative and quantitative studies. Such a research effort would observe the change in organization of the network in the face of technological change. An equally interesting direction for future research would be to observe the role of existing network structures in the design and development of technological innovations. Technology firms could benefit from an understanding of networks, work allocations within networks, and organizational variety within networks to determine which markets are most appropriate in global marketing and distribution strategies. The innovation and network *alignment* would then provide a measure for the size of addressable markets for firms marketing their products and services globally. Firms could conceivably then tailor their products and services to align with the network market structure that results in the largest addressable market.

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Figure 1

Network of Construction Specialist Firms

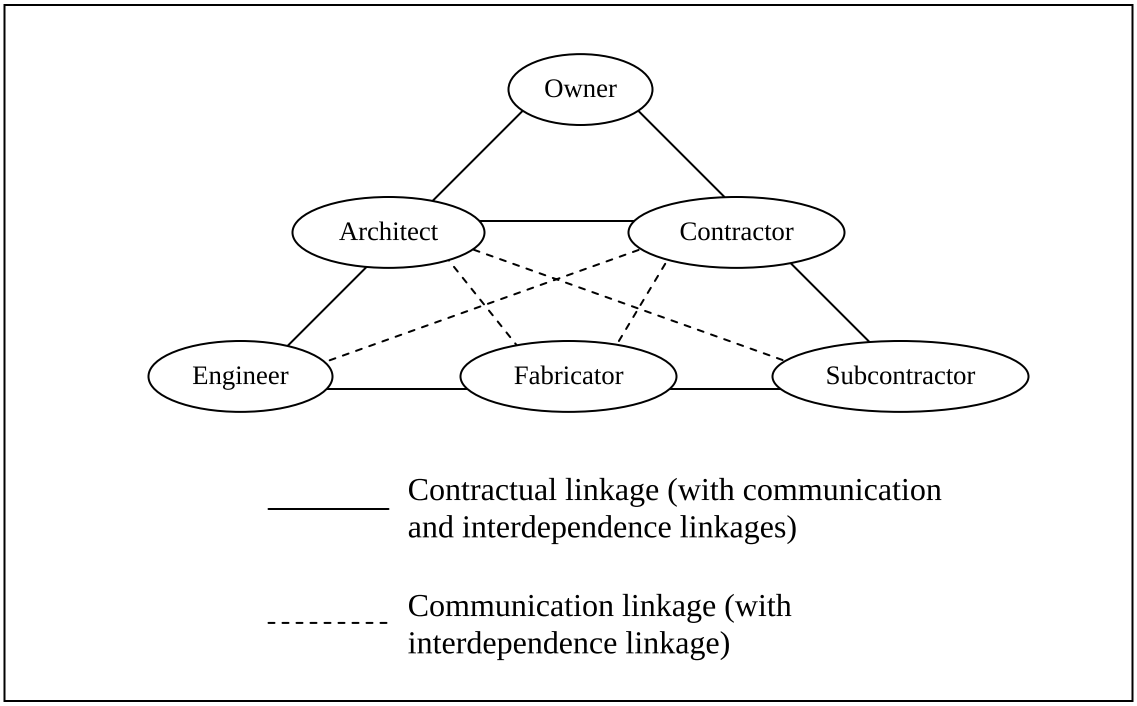

Table 1

Comparing Construction Networks in Finland and the United States

	Construction Network Country of Origin	
Construct	**United States**	**Finland**
Organizational variety	Tendency to contract from 5-6 firms per specialist type	Tendency to contract from 1-3 firms per specialist type
Sub-constructs	**United States**	**Finland**
Degree of interdependence	High	High
Organizational Boundaries	Rigid	Fluid
Interests	Firm	Network
Agent for system-level change	Self-organizing	National Funding Agencies
Industry Fragmentation	Many small firms	Few large firms

Figure 2

Alignment of Innovations to Networks in the United States and Finland