THREE PERSPECTIVES ON INNOVATION IN INTERORGANIZATIONAL NETWORKS: SYSTEMIC INNOVATION, BOUNDARY OBJECT CHANGE, AND THE ALIGNMENT OF INNOVATIONS AND NETWORKS

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I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

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Abstract

Interorganizational networks are proliferating as a form of industrial organization. However, the impact of this relatively new form of organization on diffusion outcomes and implementation processes for innovation remains poorly understood. In this dissertation I present three perspectives on innovation in interorganizational networks to address this gap in understanding. In the first, macro perspective, I examine the rate of diffusion and implementation processes for several systemic innovations in wall systems and material distribution among home building industry networks in the United States. In the second, more micro perspective, I explore the antecedents for implementing boundary object technological change among 26 firms in design and construction networks and contrast the different perspectives of designers and contractors. The third perspective involves a cross-national investigation of the diffusion and implementation of three-dimensional computer aided design tools among 82 firms in United States and Finnish design and construction networks. In this last perspective I identify cross-national differences in the allocation of work—and, as a result, the alignment of innovations and interorganizational networks. Each of the three cases employs a qualitative, case-based ground theory building research methodology. Integrating the findings from these three perspectives yields a number of constructs and propositions that highlight the importance of addressing interorganizational practices at the interfaces between firms in interorganizational networks when implementing boundary spanning technological changes. I induce a two-stage theoretical model for innovation in interorganizational networks from these findings. This dissertation contributes to a more complete understanding of innovation in interorganizational networks.

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Table of Contents

Table of Figures

List of Tables

Chapter 1

Introduction

Few would dispute the linkage between innovation and a firm's ability to maintain competitive advantage over time. Innovation has been shown to be critical to the renewal of industries (Schumpeter 1942) and to be a central mechanism by which firms secure a place in the competitive future (Van de Ven 1986). Surviving the waves of "creative destruction" theorized by Schumpeter (1942) and developing inimitable resource endowments (Amit and Schoemaker 1993) requires firms to move beyond re-investment in existing technologies to the implementation of new, innovative alternatives. Research on how firms implement new innovations has received considerable attention in the literature (Abernathy and Utterback 1978, Afuah 2001, Barley 1986, Burgelman 1983, Ettlie et al. 1984, Henderson and Clark 1990, Katz and Shapiro 1986, Mansfield 1968, Nelson and Winter 1982, Tushman and Anderson 1986). However, research on the implementation of innovations has predominantly focused on firms (Afuah 2001).

Over the last two decades a burgeoning stream of literature has emerged on the topic of interorganizational networks (Borgatti and Foster 2003). In interorganizational networks, groups of two or more firms work together in the interdependent production of goods or services (Powell 1990). In the past, adoption of the multidivisional form of organization was shown to lead to competitive advantage (Chandler 1962). Notwithstanding difficulties in collecting data on across-firm performance, researchers describe networks of firms as achieving different levels of competitive advantage when competing with other interorganizational networks (Dyer and Ouchi 1993, Gulati 1998, Gulati et al. 2000). If interorganizational networks are to achieve and maintain competitive advantage, then they must understand how to implement innovations within their networks.

Researchers find that the introduction of innovations in networks can positively impact competitive advantage in networks (Argyres 1999, Bakos 1997, Bakos and Treacy 1986, Cash and Konsyniski 1985, Johnston and Vitale 1988) while reducing the competitive advantage of other interorganizational networks (Jacobides and Winter 2005). However, for all of its received importance to the renewal of industries and the competitive advantage of firms, there is scant attention paid in the literature to the implementation of innovations in interorganizational networks. Given the growth in the use of interorganizational networks both within (Barley et al. 1992, Powell et al. 2005) and across (Kanter 1991, Pekar and Allio 1994) industries, researchers must explore the implementation of innovations in interorganizational networks. We need to develop new theories if innovation research is to remain relevant to firms in these proliferating networks.

In this dissertation I explore three perspectives of innovation in interorganizational networks; systemic innovation, boundary object change, and the alignment of innovations and networks. At a high level, each perspective explores the question of *how role interactions in interorganizational networks impact the diffusion and implementation of innovations in those networks* to fill the gap in understanding in this area. However, each treats the question from a different perspective. The theoretical generalizations increase in abstraction across the three perspectives until I introduce a theory for innovation in interorganizational networks in the third perspective.

The three perspectives on innovation in interorganizational networks explored in this dissertation are as follows:

1. The first, macro perspective is based on the implementation of two systemic innovations in home building industry networks: a new supply chain intermediary and a new pre-fabricated wall system.
2. The second, more micro perspective is based on boundary object change from a 'printed set of plans' to a 'virtual model' in implementing three dimensional computer-aided design technologies (3D CAD) in design and construction networks.
3. The third perspective is also based on the implementation of 3D CAD tools but I conduct a cross-national comparison of innovation outcomes and implementation processes in design and construction networks in the United States and Finland.

The Economic Origins of Interorganizational Network Research

Coase (1937) argued in his essay on the nature of the firm that prices determine exchanges in markets, but that individuals in firms can supersede pricing mechanisms to direct the exchange process. He argued that markets and hierarchically-organized firms could be understood under a single economic framework in terms of transaction costs of production. A firm is not in control of the allocation of resources when exchanges occur in a market. However, managers within a firm can direct production and allocate resources that are apparently in conflict with market pricing mechanisms. Coase defines the firm within the theoretical framework of markets by arguing that transaction costs determine whether exchanges occur within a hierarchically-organized firm or in the market. Organizing production within a firm can minimize transaction costs by avoiding the costs of discovering and negotiating prices in the market.

Williamson (1975) extends Coase's (1937) transaction cost framework to develop transaction cost economics. Williamson's framework considers the specificity of assets being exchanged. If the assets which are the objects of the transaction are non-specific—i.e., they have value to both parties outside of the specific transaction—then the transaction can be efficiently carried out via market exchanges. However, if co-production is based on an asset that is highly specific to the given transaction and has no value to one or both parties outside of this transaction, then the transaction is most efficiently organized within a single firm.

If two asset-specific machines are owned by different firms it can potentially lead to inefficiencies in the transactions between those firms. Two firms locked into producing goods or services together can argue over the gains from trade. When one firm invests in its asset, it will be difficult for that firm to renegotiate its price since it is locked into co-producing with the other firm's asset. When one party in an asset-specific exchange incurs costs before being paid, it creates the potential for a loss on that investment, so there is a "hold-up" problem in the economic exchange (Williamson 1975). Firms efficiently avoid the transaction costs of the hold-up problem which can occur in market exchanges by organizing asset specific production within the firm.

Building on Coase's (1937) and Williamson's (1975) concepts of markets and hierarchies, Eccles (1981) identified *quasi-firms* in the Massachusetts construction industry. Unlike the market transactions described in the transaction cost framework, in *quasi-firms* "relations between the general contractor and his subcontractors are stable and continuous over fairly long periods of time and only infrequently established through competitive bidding" (Eccles 1981, pp. 339-340). Eccles postulated that the transactions in *quasi-firm* networks represented a new mode of exchange. He described *quasi-firms* as existing between hierarchy and market modes of exchange. Stinchcombe (1985) also contributed to this debate suggesting that, in construction, contracts re-created many elements of hierarchy in this mid-range mode of economic exchange. Williamson (1985) later extended the transaction cost economics framework to include the concept of *hybrid* organizational arrangements. Arguments for *quasi-firm* and *hybrid* organizational arrangements were rooted principally in terms of economic exchanges containing aspects of both market and within-firm hierarchical governance of exchanges.

Increasing the Scope of Interorganizational Network Research

Since the discovery of the *quasi-firm* interorganizational networks (Eccles 1981), researchers have argued both the economic (Eccles 1981, 1988; Stinchcombe 1985, Williamson 1985) and sociological (Granovetter 1992, Miles and Snow 1986, Powell, 1987, 1990, Uzzi 1997) foundations of the interorganizational network form of organization. A recent definition of interorganizational networks describes them as "any collection of actors ($N \geq 2$) that pursue repeated, enduring exchange relations with one another and, at the same time, lack legitimate organizational authority to arbitrate and resolve disputes that may arise during the exchange" (Podolny and Page 1998, p. 59). Economists explore the role of transaction costs to explicate the form of organization. However, researchers adopting a sociological perspective of interorganizational networks expand the scope of interorganizational research by exploring why firms would pursue repeated and enduring exchanges and how, in the absence of legitimate organizational authority, firms resolve disputes.

Powell (1990) argues that interorganizational networks are a new form of organization. He contends that a social interaction structure exists for interorganizational network exchanges. In networks, he argues, complementary strengths are the normative basis of exchange and norms of reciprocity govern dispute resolutions. Though arguments over the form of organization continue, recent investigations of interorganizational networks have predominantly focused on exploring the role interactions between firms in an interorganizational network to elaborate on the social interaction arguments by Powell and others (Miles and Snow 1986, Powell 1987, 1990).

Researchers explore the formation process of role interactions in networks to understand how firms choose other firms with which to interact (Beckman et al. 2004; Gulati and Gargiulo 1999) and what strategies (Luke et al. 1989) and motivations (Galaskiewicz 1985) underpin partner selection. The stability of those interactions over time has received attention from researchers seeking to understand the dynamics of affiliation (Powell et al. 2005), the antecedents for the dissolution of network interactions (Baker et al. 1998), and the returns to continued interaction experience (Gulati 1995). A large body of researchers has explored the impact of interaction experience in networks on the flow (Appleyard 1996), transfer (Mowery et al. 1996), spilling over (Uzzi and Gillespie 2002) and sharing (Faulkner and Anderson 1987, Möller and Svahn 2004) of knowledge across network role interactions.

Moving beyond understanding formation, durability, and learning in interorganizational networks, a number of researchers have explored the processes by which interactions between firms in networks are governed. Researchers ascribe the endurance of networks to historical context of interactions (Scott 1987) and to relational embeddedness (Granovetter 1992, Uzzi 1997, Uzzi and Gillespie 2002). These investigations provide the foundation for the development of theories of interorganizational network governance (Larson 1992, Jones et al. 1997).

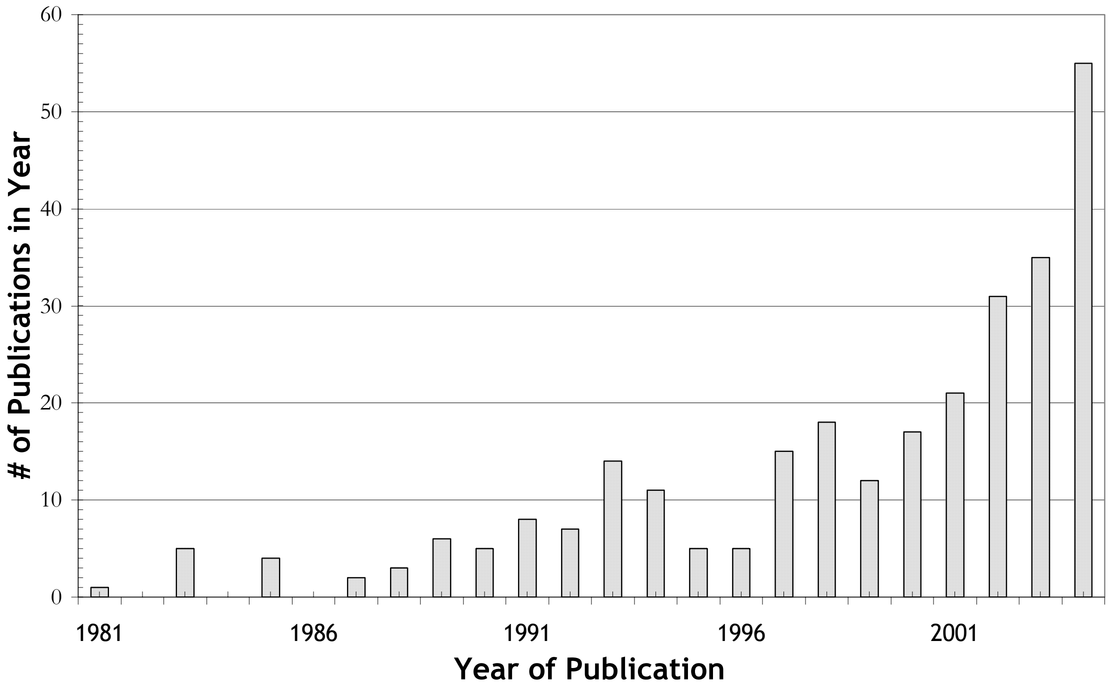
Sociologically-driven theories explaining why firms "pursue repeated, enduring exchange relations" (Podolny and Page 1998, p. 59) and the processes by which firms in networks "resolve disputes that may arise" (Podolny and Page 1998, p. 59) contribute to a more complete understanding of the interorganizational network form of organization than economic theories alone. However, in focusing on the formation, durability, learning and governance of interorganizational network role interactions, they largely fail to explore how the role interactions in a network may impact the creation, adoption and implementation of innovations.

Increasing the Scale of Interorganizational Network Research

In addition to research aimed at refining concepts of interorganizational networks, researchers have documented a proliferation of these networks in industry (Barley et al. 1992, Powell et al. 2005). Growth in the use of the interorganizational network form of organization has not been confined to a small number of industries. Researchers have identified interorganizational networks in a diverse range of industries; including, advertising (Baker et al. 1998), aviation (Argyres 1999), the automotive industry (Gulati and Garguilo 1999), biotechnology (Barley et al. 1992, Powell et al. 1996, Zucker et al. 1996), the chemicals industry (Ahuja 2000), construction (Eccles 1981, Stinchcombe 1985), electronics (Afuah 2001), the fashion industry (Uzzi 1997), financial services (Eccles and Crane 1988, Sydow and Windeler 1998, Jacobides and Winter 2005), healthcare (Luke et al. 1989), the motion picture industry (Faulkner and Anderson 1987, Lampel and Shamsie 2003), pharmaceuticals (Powell 1998, Zeller 2002), and watch-making (Jacobides and Winter 2005). The growth in use of interorganizational networks in lieu of traditional hierarchically-organized firms interacting at arm's-length in markets is growing both within and across industries (Kanter 1991, Pekar and Allio 1994). Researchers have observed a rise in the use of interorganizational networks among entrepreneurial ventures (Larson 1992), among large corporations in the United States (Beckman et al. 2004, Pekar and Allio 1994), and among multinational enterprises (Goerzen and Beamish 2005, Mowery et al. 1996).

In parallel with research on the proliferation of networks within and across industries, research and publishing on the network form of organization has grown considerably since their first discovery. Since Eccles' (1981) identification of *quasi-firms* in the Massachusetts home building industry, researchers have published 280 journal articles on the subject of interorganizational networks. Figure 1.1 below illustrates the growth in publication on interorganizational networks by showing the number of journal articles published in each year since 1981 that had 'business networks' or 'interorganizational networks' either in the title of the article, as a keyword for the article, or in the abstract of the article. Beginning in the mid-1990s, publishing on interorganizational networks began to increase rapidly.

Figure 1.1 – Number of Journal Articles Published Annually on Interorganizational Networks (1981 – 2004)



Innovation in Interorganizational Networks

It is striking given the scope and scale of research on interorganizational networks, that in the period from 1981 through 2004 only 14 articles appeared that addressed the topic of innovation in interorganizational networks. Researchers have long hailed innovation as being central to the renewal of firms (Mansfield 1968) and industries (Schumpeter 1942). However, the question of how this new form of organization impacts the innovation process remains to a large extent unexplored. The few interorganizational network researchers addressing innovation tend to focus on the innovativeness of a network of firms. In other words, researchers explore the production of novelty endogenously within networks as opposed to the adoption and implementation of innovations produced exogenously. Studies of the innovativeness of interorganizational networks have resulted in conflicting findings.

Powell and colleagues (1996) identified networks within the biotechnology industry as the loci for innovation. Their arguments were rooted in the fact that organizations do not contain all the knowledge that they need. Interorganizational networks provide access to relevant knowledge not available internally or externally for purchase. Therefore, organizing into interorganizational networks enables firms to share and exploit asymmetries in knowledge. Building and leveraging an inter-firm sharing of knowledge enabled firms in networks to build new capabilities and outperform firms that were not connected in networks. Ahuja (2000) confirmed the findings of Powell and his colleagues in the chemicals industry. He found that connectedness through direct and indirect ties into networks increased organizations' performance and, hence, he posited, their innovativeness.

In two later papers about learning in biotechnology and pharmaceutical networks, Powell and his colleagues (Powell 1998, Powell et al. 1999) caution about the difficulty of making learning portable in interorganizational networks. Zeller (2002) investigated the impact of developing research and development interorganizational networks in the Swiss pharmaceutical industry and observed a slowdown in the innovativeness of the firms. In other industries, the impact on learning and innovativeness of adopting the interorganizational network form of organization has also been found to have negative effects. Lampel and Shamsie (2003) found an evolutionary stagnation in the ability for firms in the motion picture industry to innovate. Gann and Salter (2000) describe broken learning and feedback loops in construction industry networks that negatively impact their ability to innovate.

There is clearly some question as to whether interorganizational networks enable firms to become more innovative or whether they are a liability to innovativeness. Gulati (1998) suggests that it is exceedingly difficult to attribute the performance of an interorganizational network to any single factor. Perhaps the range in outcomes regarding the innovativeness of interorganizational networks lay in using performance as the indicator of innovativeness. A surprising finding in a paper by Powell and his colleagues (1999) may suggest a mediating factor. They indicate that "perhaps the most interesting finding is that there are decreasing returns to network experience" (p. 151). A more complete exploration of the question of innovativeness in interorganizational networks may lie in exploring the impact of the maturity of role interactions on performance. Lampel and Shamsie (2003) explore this question investigating longitudinal data on the evolution of the Hollywood motion picture industry from hierarchy to interorganizational networks. Their finding that "the dark side of new organizational forms in Hollywood is an evolutionary stagnation in the craft of making movies" (p. 2206) would seem to imply rather strongly that innovativeness is negatively correlated with the maturity of role interactions.

These findings are interesting and have clear implications for understanding and leveraging interorganizational networks as a form of organization. However, they do not address the adoption and implementation of an innovation developed outside of the network. Previous research finds that the introduction of a new technological innovation within an organization can restructure role interactions (Barley 1986, Dougherty 1992), alter work patterns (Barley and Kunda 2001, Leonard-Barton 1987, Orlikowski 1992, Orlikowski et al. 1995), and, in doing so, cause a restructuring of the technology (Leonard-Barton 1988, Orlikowski 1992, Orlikowski et al. 1995). If the implementation of a technology propagates far-reaching changes across an organization, its work, and the implemented technology, then surely the propagated changes will intensify as they attempt to cross organizational boundaries within networks. Some researchers argue that innovation studies must look beyond focal firms (Afuah 2001). Afuah (2001) identified disruptions across buyer-supplier relationships as a consequence of innovations in the reduced instruction set computing industry. Waves of change that propagate across organizational boundaries in interdependent interorganizational networks may require multiple iterations of mutual adjustment at the interfaces that bridge role interactions. Through the investigation of systemic innovation, boundary object change, and the alignment of innovations and networks, this dissertation seeks to develop a more complete understanding of innovation in interorganizational networks.

Format and Flow of this Dissertation

The results presented in this dissertation follow the "three journal paper" format. This is an increasingly common form of dissertation presentation which has the benefit of enabling the researcher to more quickly publish from his or her dissertation work. Chapters 2, 3 and 4 are each crafted to act as a stand-alone document publishable in a peer-reviewed academic journal. Each paper has its own Abstract, Introduction, and Conclusions section. However, I have aggregated the references from each paper into a single Reference chapter at the end of this dissertation.

In Chapter 2 of this dissertation, the first paper presents a perspective on systemic innovation in interorganizational networks. This paper was co-authored with Professor Raymond Levitt and was included as a peer-reviewed chapter in a book entitled Innovations: Project Management Research 2004 edited by Dennis Slevin, David Cleland and Jeffrey Pinto and published by the Project Management Institute (Taylor and Levitt 2004). Because the paper was written with a co-author, the paper uses plural possessive pronouns such as "we," "us" and "our" as opposed to the singular possessive pronouns such as "I," "me" and "my" used elsewhere in the dissertation. This paper represents an early exploratory study which motivated my primary data collection effort. The proof of concept model included in this paper served as the basis for my dissertation proposal defense in April 2004.

In Chapter 3 of this dissertation, the second paper presents a perspective on boundary object technological change in design and construction networks. This paper was designed for submission to an academic journal that bridges technology and innovation management research with organizational theory research. I hope to publish this paper in Research Policy, the Journal of Product Innovation Management, or IEEE Transactions on Engineering Management. In this paper I explore how networks of design and construction firms successfully implement technological change that crosses organizational boundaries.

In Chapter 4 of this dissertation, my third paper offers a perspective on the alignment of innovations and interorganizational networks. This paper introduces a new theory for innovation in interorganizational networks. It was designed for submission to an organizational theory-driven academic journal such as Organization Science, Academy of Management Journal, or Management Science. In the research, I conduct a cross-national investigation of 3D CAD diffusion and implementation in construction networks in the United States and Finland. I identify a set of high level constructs and propositions that mediate the innovation implementation process in interorganizational networks. I build a two stage grounded theoretical model of innovation in interorganizational networks in the paper.

Chapter 5 of this dissertation summarizes the theoretical contributions of the three articles contained in this dissertation. Chapter 6 suggests possible directions for future research on innovation in interorganizational networks. Finally, Chapter 7 of this dissertation contains the bibliographic information referenced throughout the dissertation.

Chapter 2

Understanding and Managing Systemic Innovation in Project-based Industries[1]

Abstract

Traditional industries (e.g., aerospace and pharmaceuticals) that once organized their activities into functional hierarchies are evolving into entities with project-based forms of organization in which teams of specialists from both inside and outside the firm report to project managers. Emerging industries (e.g., biotechnology and information technology) are also adopting project-based forms of organization. Researchers term this emerging proliferation of organizational forms between pure markets and pure hierarchical organizations the "swollen middle" (Hennart 1993).

Though much is known about innovation in traditional, hierarchical organizational structures, little research to date explores the issues associated with innovation in the project-based organizations that populate the swollen middle. As the outsourcing of specialized skills increases, multiple interdependent firms must often change their processes to realize the potential of product and process innovations (e.g., supply-chain

[1] This paper was co-authored with Professor Raymond Levitt and was published as a peer-reviewed chapter in a book on innovation in project management. The citation is as follows:

Taylor, J., R. Levitt. 2004. Understanding and managing systemic innovation in project-based industries. D. Slevin, D. Cleland, and J. Pinto, eds. *Innovations: Project Management Research 2004*. Project Management Institute, Newton Square, PA, 83-99.

management, enterprise resource planning, or component prefabrication). Although these innovations may hold the promise of significant increases in profitability as well as in overall productivity, data shows that these improvements—what are known to researchers as *systemic* innovations—diffuse slowly in project-based industries. Our research explores the structural mechanisms inherent in project-based forms of organizational structure and operations that impact the diffusion of systemic innovations.

Expanding our understanding of this phenomenon is critical as firms and industries continue to evolve into project-based forms of organization. In this paper, we explore these structural mechanisms in order to develop a proof-of-concept explanatory model for understanding why systemic innovations diffuse more slowly than incremental innovations in project-based industries. Our research focuses narrowly on innovations in residential building, though we seek to generalize the model we have developed so that we can apply it to any project-based firm or industry. In this paper we:

1. Delineate the concepts of *incremental* and *systemic* innovations in the project-based industry context.
2. Review the building industry literature on innovation.
3. Present outcome and process evidence from our case-based research on *incremental* versus *systemic* innovations in the United States (US) residential homebuilding industry.
4. Introduce a proof-of-concept model for *systemic innovation* in project-based industries.

Introduction

Project-based industries are among the largest industries in the global economy. These include the construction, aerospace, motion picture, pharmaceutical, healthcare, and defense industries. As mentioned, project-based forms of organization are becoming prevalent in such new and emerging industries as biotechnology and information technology. Innovation research to date, however, has largely focused on traditional, hierarchical organizations. When project-based industries are included in innovation studies, the analyses rarely explore—with any useful meaning—the differences in mechanisms and rates of innovation that emerge between traditional, hierarchical forms of organization and project-based forms of organization. In our research, we explore the differences in rates of innovation—and the structural mechanisms that produce them—for different kinds of innovations in the project-based residential building industry.

Residential building is the largest market segment in the US construction industry. In 2003, residential building revenues exceeded half of the US$882 billion spent on construction nationwide (Plunkett 2003). Residential building, along with the construction industry in general, is often described as a laggard in adopting new products and processes. The construction industry's innovation literature contains a lengthy debate on whether or not the industry is innovative. Research to date fails to consider how the structural mechanisms inherent in project-based forms of organization might contribute to resolving this debate. However, upon closer examination, research describing innovations with minor changes in the product (*incremental innovations)* typically find the industry to be on par with manufacturing industries, whereas research on product and process innovations that require multiple firms to change their processes (*systemic innovations*) find the industry to indeed be a laggard adopter.

Systemic innovations that require multiple companies to push forward change in a coordinated fashion include the recent advances in supply-chain management, the increasing use of enterprise resource planning, the move to sustainable building practices, and the prefabrication of component systems. Traditional, hierarchically organized manufacturing industries have adopted these innovations efficiently and captured significant gains in productivity. When similar innovations were promoted in the building industry, these failed to diffuse rapidly or widely. In the domain of supply-chain management, studies have illustrated the way that lean production techniques from the manufacturing industry were applicable in the building industry (Alarcón 1993). Other studies demonstrated that these techniques were adopted slowly and ineffectively in the building industry (Lillrank 1995). This paper will explore a set of structural mechanisms inherent in project-based industries in order to begin to build an explanatory model for the diffusion of systemic innovations. By gaining insight into the mechanisms that impact the adoption of systemic innovations in project-based industries, we can begin to capture the productivity gains that manufacturing industries have achieved through their broad adoption of systemic innovations.

In this paper, we apply the concepts of *incremental* and *systemic* innovations to a project-based industry and position our study in the body of research on innovation in project-based industries. This paper establishes with outcome evidence that in the US residential construction industry systemic innovations diffuse more slowly than incremental innovations. Our research uses two case studies to reveal a set of constructs that provide the foundation for an explanatory proof-of-concept model for the diffusion of systemic innovation in project-based industries. We hope this model will provide the basis for improving our ability to understand, predict, and make relevant interventions for overall productivity-enhancing systemic innovations in project-based industries.

Background

The idea of promoting systemic innovations in the US residential building industry is not new. In 1927, R. Buckminster Fuller invented the Dymaxion house to solve the perceived need for a mass-produced, affordable, and environmentally efficient house (Fuller 1983). The Dymaxion house, whose name signified *dynamic maximum tension*, used a tension suspension system from a central column to support an aluminum external structure. This design was a significant departure from existing building practices in the industry. It required a change in building materials for some parts of the home, most notably the exterior walls. But, more importantly, it required a change in the building process for many of the trade contractors without requiring a change in building materials. Many of the component systems in the home—plumbing, mechanical, and electrical—were to be prefabricated in the factory. The innovation was designed to meet the need of the two billion new homes that Fuller expected to be needed over the following eighty years (Fuller 1928). Today, nearly eighty years later, Fuller's systemic innovation for the industry has yet to be realized.

Not until 1945 was the first Dymaxion house built. It was constructed in Wichita, Kansas for Beech Aircraft. The end of World War II provided an opportunity to use the infrastructure constructed to create military aircraft to mass-produce the first Dymaxion house. Beech analyzed the prototype house in Wichita and estimated that they could produce and sell 20,000 of Fuller's houses per year at a selling price of $1,800. Soon after the innovation was announced to the public, 36,000 orders were placed for Dymaxion houses. However, not a single Dymaxion house was constructed after the prototype because (Fuller 1983):

- Building contractors were unable to coordinate in such a way as to construct several dwellings in one day.

- Building codes did not explicitly permit the design.
- Electrical and plumbing contractors refused to change their business practice, insisting that they be paid both to disassemble the prefabricated work and to reassemble it.

Most systemic innovations, like the Dymaxion house, fail to diffuse in the residential building industry even though many can offer demonstrable benefits in terms of time, cost, quality, and/or safety. Those that survive suffer from poor adoption even though some innovative solutions have proven to add significant, measurable value to the industry (Taylor and Björnsson 2002). Ironically, the only surviving Dymaxion house sits in the Henry Ford Museum as an example of a mass-production home. It might just as easily symbolize the failure of systemic change in the project-based building industry.

In a study of the motion picture industry, Lampel and Shamsie (2003) concluded that the move from hierarchical forms of organization to project-based organizations created "an evolutionary stagnation in the craft of making movies" (p. 2206). Clearly, the residential building industry has similar difficulty with systemic change. We contend that this is due to structural characteristics inherent in organizing work around projects. If our conjecture is true, then the fact that industries are evolving into project-based forms of organization makes this research critical. If industries are to take advantage of the flexibility afforded by project-based organizational forms, they must also understand the difficulties that will emerge over time for the diffusion of systemic innovations.

Review of the Building Industry Innovation Literature

Few, if any, innovation studies directly explore the fundamental differences between project-based and non-project-based industry structures. However, some researchers have called for more rigorous innovation studies that focus on the project-based nature of the building industry (Gann and Salter 2000). Perhaps this derives from the fact that most innovation studies in the building industry have focused on the *behavior of the firm* instead of the *structural characteristics of the market*. As previously mentioned, this paper explores the structural mechanisms that differentiate traditional, functionally organized industries from project-based industries that affect the diffusion rate for different types of innovations.

Innovation research generally conforms to either *adopter*-oriented studies or *macro*-oriented studies (Attewell 1992). Adopter-oriented 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). In the building industry, most of the literature investigates adoption behavior at the firm level.

Unlike research oriented towards firm behavior, macro-oriented research focuses on a population of firms' *ability* to adopt. This research tends to focus more on the structural characteristics of the adopting population. In the broader innovation literature, mathematical models are often employed to understand the rate and pattern of adoption across a pool of potential adopters. Research on market-level mechanisms is lacking for project-based industries. None of the papers we have identified in the building industry innovation literature attempt to model the market-level processes.

Table 2.1 summarizes the academic literature on market-level innovation ability in the building industry. The papers reviewed and listed in the table include relevant papers that we identified in the key building industry academic journals. Since our own research investigates market-level mechanisms, we will explore the papers listed in Table 2.1 in more detail. It should be noted, however, that a substantial literature on firm behavior relating to innovation exists for the building industry. This literature will not be discussed in this paper.

Table 2.1 - Market-oriented Building Industry Innovation Literature Summary

Author	Research focus	Key findings
Arditi and Tangkar (1997)	Study of 30-year innovation rate in construction equipment.	Between 1962 and 1992 the number of new models increased. All the innovations were incremental.
Blackley and Shepard (1996)	Observation of incremental innovations among 417 homebuilders.	Industry fragmentation does not impact innovation adoption rates for incremental innovations.
DuBois and Gadde (2002)	Investigation of construction industry productivity and innovation.	Industry is loosely coupled; concludes that diffusion is forestalled.
Gann, Wang, and Hawkins (1998)	Investigation of the impact that regulations for energy-efficient housing have on innovation.	Imposed regulations in the United Kingdom's (UK) building industry neither inhibit nor stimulate innovation.
Gann and Salter (2000)	Examination of 30 construction firms to understand innovation in that industry.	Discontinuous nature of construction leads to broken learning and feedback loops.
Lutzenhiser and Biggart (2003)	Study of energy efficiency diffusion in commercial building.	Only incremental innovation is possible in the building industry, due largely to the industry's fragmented nature.
Oster and Quigley (1977)	Survey of the impact of 1970's regulations on diffusion across four innovations.	Education level of building officials, the extent of unionization, and the size of the firm affect diffusion.
Winch (1998)	Investigation of innovation in the British construction industry.	Relatively low rate of innovation may be due to structural features of industry that can simultaneously enable too much and too little innovation.

The eight publications on market-level innovation in the building industry can be broadly classified as relating to the impact of regulation on diffusion of innovations, the impact of the decentralized industry structure on innovation, and the examinations of innovations diffusing through the industry. We discuss each of these research trusts below.

Impact of Regulation on Diffusion of Innovations

Oster and Quigley (1977) and Gann and his colleagues (1998) investigated the impact of industry regulations on the homebuilding industries in the US and the UK. In testing for a number of variables across four innovations, Oster and Quigley's research found that diffusion rates are significantly impacted by the education level of the chief building official, the extent of unionization in the population of firms being studied, and the size of the adopting firm. Their analysis points to the fact that building codes and regulation can slow the diffusion rate for an innovation. Gann and colleagues, in a study of the diffusion of energy efficiency in homebuilding, found that regulations in the UK neither inhibit nor stimulate the diffusion of energy efficiency.

Impact of Decentralized Industry Structure on Innovation

Citing the work of Weick (1976) on loose coupling in educational organizations, a number of studies seek to understand the impact of the decentralized structure of the industry on innovation. DuBois and Gadde (2002) claim that the construction industry meets the criteria of a loosely coupled organization and therefore localized adaptations occur; they add, however, that "loose coupling could also forestall the spread of advantageous mutations" (p. 628). Other work by Gann and Salter (2000) and Winch (1998) makes a related point that the decentralized industry structure facilitates innovation at the project level while, at the same time, making it difficult to diffuse across the industry.

Examination of Innovations Diffusing in the Industry

Surprisingly few papers investigate how specific kinds of innovations are diffused in the building industry. Our literature search identified three papers that explore innovations in the industry as part of our effort to understand the market-level structural mechanisms at work. Arditi and Tangkar (1997) explored innovations in construction equipment over a 30-year period to understand the rate and the types of innovations that are diffused in the construction industry. These authors found that innovations in heavy equipment were all incremental in nature and that the rate of the introduction of new models—a proxy for innovation rate—had increased. Blackley and Shepard (1996) looked at the way 417 homebuilders adopted innovations; their analysis did not support the hypothesis that the fragmented industry structure reduces the diffusion rate for innovations. It must be noted that the Blackley et al. study exclusively investigated incremental innovations.

Finally, Lutzenhiser and Biggart (2003) completed an exhaustive analysis of innovation in the commercial building industry in order to understand how the market structure impacts the diffusion of energy efficiency. They found that all innovations in the building industry were incremental in nature and argued that the structure of the industry inhibited innovation. Their findings agreed with our own findings on the lack of research on market-level mechanisms, stating that “aside from a bit of work on tax and regulatory policy, relatively little attention has been given to market-level processes” (p. 3). In their final analysis, Lutzenhiser et al. describe the industry actors as each having a “separate social world with its own logic, language, actors, interests and regulatory demands” (p. 47).

Summary of Market-oriented Research

These eight papers on market-level innovation mechanisms provide a point of departure for the work described in this paper. A gap exists in the innovation literature in the amount and in the scope of research on market-level issues. The regulatory and normative barriers that separate the trade contractors in the building industry provide a key mechanism for understanding the diffusion of systemic innovations. The work to date that focuses on the impact that regulations have had on the diffusion of innovations in project-based industries does not explore what specific mechanisms related to regulation meaningfully impact diffusion. The work on the decentralized structure of the industry seeks to understand why some innovations diffuse more readily than others. This paper extends this work to consider the impact of the scope of the innovation (incremental vs. systemic) on the rate of diffusion. Finally, the work on cases of diffusion in the construction industry explicitly or implicitly implies that systemic innovation is not possible in the fragmented building industry. We take the regulatory, decentralization, and fragmentation arguments as a starting point to explore the finer-grained structural mechanisms impacting the rate of diffusion for systemic innovations in project-based industries.

Incremental vs. Systemic Innovation in Project-based Industries

Most research on innovation in the building industry, as previously mentioned, focuses on incremental innovations. Incremental innovations are those that reinforce the existing product or process and provide a measurable impact on productivity, such as the transitioning of homebuilding from stick-built construction to the use of prefabricated wall trusses. In the case of incremental innovations, productivity for individual components can increase while overall productivity may increase, decline, or remain unchanged. Systemic innovations, on the other hand, refer to innovations that reinforce the existing product but necessitate a change in the process that requires multiple firms to change their practice. Systemic innovations typically enable significant increases in overall productivity over the long term. But these may create switching or start-up costs for some participants and reduce or eliminate the role of others. Examples of systemic innovations include virtual design and construction, supply chain integration, and in homebuilding, prefabricated subcomponent wall systems.

Henderson and Clark (1990) introduced the concept of architectural innovation (what we describe in this paper as systemic innovation). They investigated several seemingly straightforward innovations that resulted in significant consequences for the photolithographic alignment equipment industry. Their goal was to understand what characteristics of those innovations were unique. Their research suggested that the link between the core concepts and the components in a product or process innovation were important factors in describing the landscape of types of innovations. This convention is particularly useful for exploring innovations in the project-based residential building industry. Table 2.2 illustrates the Henderson et al. innovation framework and gives examples of building industry innovations for each category.

Table 2.2 - Innovation Framework Detailing Categories of Innovation Scope

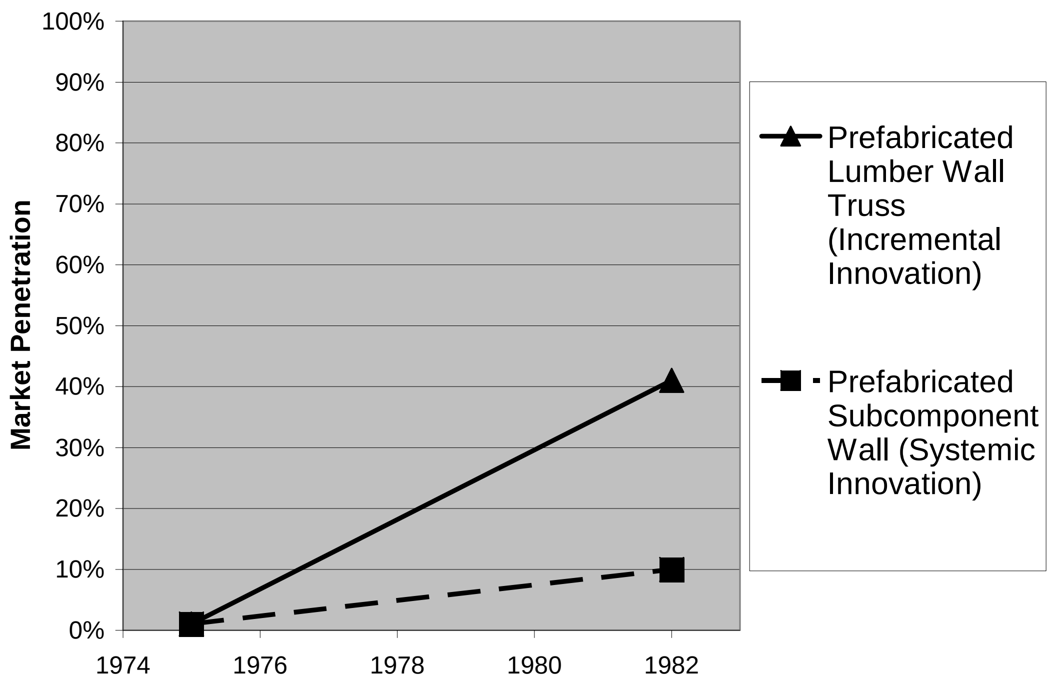
<table>
<tr><td colspan="2"></td><td colspan="2">Core concept</td></tr>
<tr><td colspan="2"></td><td>Reinforced</td><td>Overturned</td></tr>
<tr><td rowspan="2">Link between core concepts & components</td><td>Unchanged</td><td>Incremental innovation
Example: Lumber wall truss frame replacing conventional stick-built lumber wall frame</td><td>Modular innovation
Example: Extruded metal truss frame replacing conventional stick-built lumber wall frame</td></tr>
<tr><td>Changed</td><td>Architectural (Systemic) innovation
Example: Prefabricated wall frame with HVAC, plumbing & electrical components replacing conventional stick-built lumber wall frame</td><td>Radical innovation
Example: Geodesic dome frame replacing conventional stick-built lumber wall frame</td></tr>
</table>

Modular and radical innovations require significant changes in the product. In cases of modular and radical innovations, new firms will typically enter the market to exploit the construction of these new products. In these cases, regulatory concerns play a key role in determining the acceptance of a new product entering the residential building market. On the other hand, incremental and systemic innovations require subtler changes. The existing firms in the industry are required to modify their building process. And because the existing product concept is reinforced, issues of code compliance are typically not raised. In manufacturing industries, systemic innovations can diffuse quickly as Henderson and Clark (1990) discovered in their analysis of the photolithographic alignment equipment industry. Interesting issues arise at the intersection of work within and across project teams for incremental and systemic innovations. These issues begin to explain the problems related to the diffusion of systemic innovation.

To validate our conjecture that systemic innovations diffuse more slowly than incremental innovations, we sought data on building industry innovations. A special report by the US government (United States Congress Office of Technology Assessment

1986) revealed some striking trends in systemic versus incremental innovations in the US residential building industry. It reported that a wall truss incremental innovation in the lumber trade diffused rapidly through the US construction industry over a seven-year period. The report, however, describes a prefabricated subcomponent wall containing lumber, plumbing, electrical and mechanical components—hence a systemic innovation—diffusing at about one-quarter the rate over the same period. This diffusion data is illustrated in Figure 2.1.

Figure 2.1 - Comparison of Incremental & Systemic Innovation



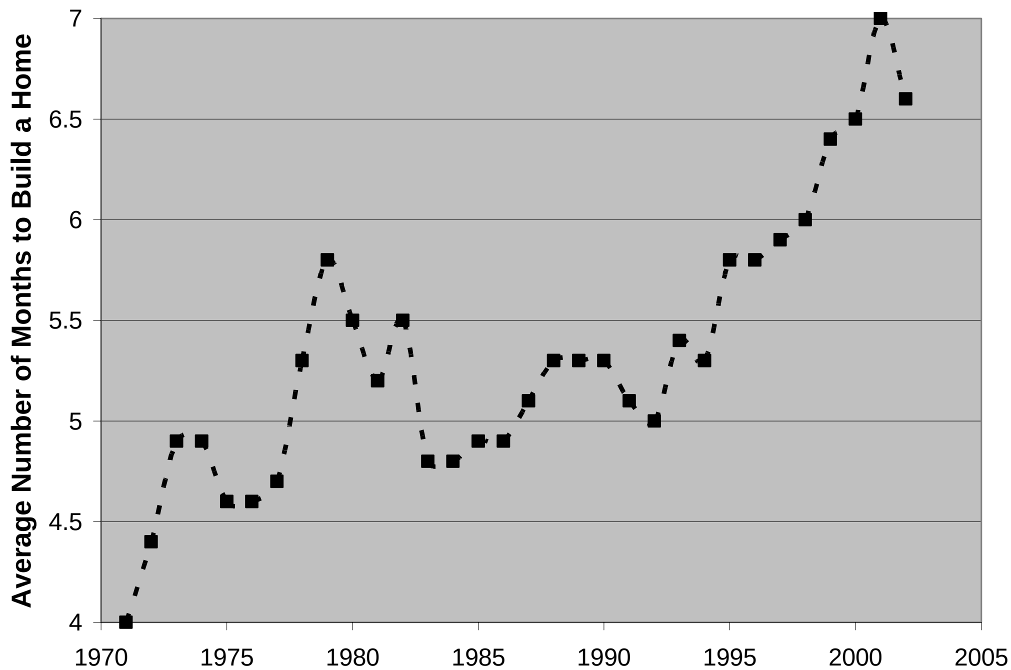
Clearly in this case, the incremental wall truss innovation diffused much more quickly than the systemic prefabricated subcomponent wall innovation. But we explored the issue further to understand what factors impacted the adoption of incremental innovations more quickly than systemic innovations. Taking the roof truss as an example of an incremental innovation, we find in a National Association of Homebuilders Research Center report (O'Brien et al. 2000) that:

> "The structural system is designed and fabricated with little concession to the design and fabrication of mechanical, electrical, and enclosing systems, and little thought to the overall production efficiency. Within each major building system, various stages of component prefabrication, assembly simplification, and labor time reduction are practiced. The plate roof truss is a common example of structural subsystem component integration. Equally common is the modification of these trusses by building trades installing ductwork, plumbing, or electrical wiring. The advantage of this approach is the reduction of development costs. However, this comes at the expense of subcontractors and the homebuilder." (p. 39)

This finding suggests that products and processes for individual trades are being optimized through incremental innovations. However, the net sum of all of these incremental innovations may be a *decrease* in overall productivity of the construction project. This would be extremely unwelcome in an industry already known for its low profit margins. On average, the savings potential of removing one day from the build schedule for a single-family home in the United States is $291 to a homebuilder (Caldeira 2002a). Others have estimated the cost savings of removing a day from the build schedule from $50 to $500.

We examined this further to determine if the US housing industry had experienced an increase in construction duration over the last 30 years. What we found was that duration had increased from an average of 4 months in 1971 to an average of 7 months in 2001 (Plunkett 2003 — see Figure 2.2). This is extraordinary given the fact that homes are routinely built in two days in trade show demonstrations (Caldeira 2002b).

Figure 2.2 - Average Duration of Single Family Home Construction in the United States (1971-2002)



We further postulated that perhaps the industry had become more fragmented over the same period. In the period from 1992 to 1997, the number of contractors in the industry grew by about 10 percent (United States Census Bureau 1997), whereas the increase in the average project duration was about 15 percent. These findings were consistent enough that we began to suspect that the fragmented market structure might negatively affect the diffusion of systemic innovation. What is also interesting to note is that Blackley and Shepard (1996), in a study involving the diffusion of incremental innovations among 417 homebuilders, found that diffusion was not impacted by fragmentation. This supports our assertion that according to the project-based industry structure, systemic and incremental innovations are impacted differently by regulation, decentralization, and fragmentation.

Proof-of-Concept Model for Systemic Innovation Diffusion

Research Method

Based on this evidence, we began exploring the structural mechanisms impacting the diffusion of systemic innovations using the case study research method. Our goal was to identify the finer-grained structural mechanisms related to regulation, decentralization, and fragmentation that impact the diffusion of systemic innovations in project-based industries. From this evidence we sought to build a grounded theoretical model to explain the slower diffusion rate for systemic innovations in project-based industries. The evidence presented so far illustrates *outcome* data from cases of incremental and systemic innovation diffusion. The case study research method enabled us to further explore this phenomenon by focusing on the *process* of diffusion in the detailed analysis of two cases of systemic innovation.

Our multiple case-study analysis focused on two systemic innovations in the US homebuilding industry. The goal of this case research was to develop a proof-of-concept explanatory model explaining the diffusion of systemic innovations. As such, we elected to use literal replication logic and focused on two cases that we believed would provide similar results. Since we hoped to build an explanatory theoretical model that leveraged existing models for diffusion, we chose the cases based on their ability to support analytical generalization, as opposed to statistical generalization. The case research involved collecting relevant documentation, investigating third party documentation about the innovations (e.g., from industry reports by the National Association of Homebuilders and from trade magazines such as *Builder* and *Big Builder*), conducting focused interviews, and making direct observations. Since we triangulated the evidence gathered from multiple cases and multiple data sources within cases, we controlled our construct validity and internal validity. To improve the external validity of the research findings, we used literal replication logic.

Cases Investigated

We focused on two US residential construction cases that both required the multiple trade contractors to change their business processes; these cases required little, if any, change in the actual product. One case involves an innovation in supply-chain management that focuses on improving information and material flows between large builders and manufacturers for plumbing, electrical, and mechanical supplies. The second case includes an innovation in wall construction that focuses on prefabricating the wall system in a controlled factory environment with lumber, plumbing, electrical, and mechanical subsystems. For purposes of confidentiality, the names of these firms and details of their innovation are not disclosed.

Case 1: Supply chain systemic innovation at Supply Chain Innovators, Inc.

In the single-family residential homebuilding industry, subcontractors typically purchase the materials required for their daily work activities. Even in cases where homebuilders become large enough to have significant purchasing power with manufacturers, subcontractors typically purchase the materials from local distributors. This means that significant amounts of unnecessary inventory are held at distributors for each trade contractor. Furthermore, this requires, as one builder—who works for a large firm—we interviewed stated, a “convoy of trucks to arrive on the job site every day, each dropping off only a few material supply items.”

Supply Chain Innovators, Inc. (not the studied firm’s actual name) was formed in order to improve the distribution of building materials to large builders. They created a material distribution hub where goods from multiple manufacturers could be temporarily warehoused and delivered to the job site. However, rather than bringing the materials for only one trade at a time, Supply Chain Innovators created material kits that contained all the materials required for the mechanical, electrical, and plumbing subcontractors for the day. These material kits were delivered using just-in-time logistics and were ordered and paid for by the large builders. Builders liked the solution because it saved them money and reduced their wait for materials. Manufacturers liked it because they received material orders with significant lead times, enabling them to produce to-order instead of producing goods for their distributors to stock as inventory.

The mechanical, electrical, and plumbing contractors who used the distribution system found it a profitable alternative. However, each time Supply Chain Innovators started a new homebuilding project, they found a different set of trade contractors working on the project. Even if by chance the next project had the same mechanical subcontractor, the plumbing and electrical subcontractors varied. This constant change in the mix of firms on a project site created a significant impediment for the rapid diffusion of Supply Chain Innovators' solution. However, it also created difficulties for project managers. Project managers expected overall productivity on the site to increase when they moved to Supply Chain Innovators' just-in-time delivery system. Instead, they found that the mechanical, electrical, and plumbing teams working on the projects could not effectively develop routines for their interdependent work activities.

Not until Supply Chain Innovators made the decision to vertically integrate their operations did they achieve a diffusion rate that led to profitability. They purchased mechanical, electrical, and plumbing subcontractors and began installing the materials flowing through their own distribution channel. In this way, they could be certain that the knowledge of how a group of project teams needs to interact in order to exploit their innovation could be maintained from one project to the next. This enabled the on-site productivity improvements that the project managers where hoping to gain from their adopting the Supply Chain Innovators solution.

Case 2 – Wall system systemic innovation at Wall System Builders, Inc.

Roof trusses, wall trusses, and floor trusses are commonly used in single-family residential homebuilding in the US. However, the use of prefabricated wall systems is rare. Prefabricated wall systems include prefabrication of subcomponent systems that include mechanical, electrical, and plumbing in addition to structural lumber. In other instances, this can include the insulation, drywall, windows, and interior/exterior finishes. Wall System Builders, Inc. (not the studied firm's actual name) was a regional builder who decided to incorporate prefabricated wall systems into their already existing homebuilding business.

In attempting to incorporate pre-fabrication into their building practice, Wall System Builders ran into some unexpected difficulties in getting the trade contractors to coordinate their work. They found that the best way to build a prefabricated wall system was to have the lumber, plumbing, electrical, and mechanical teams fabricate their systems in their warehouse. This was a significant departure in the building process for the trades involved and created difficulties in effectively managing the project. Project managers found that the productivity enhancements from reengineering the process were lost in the extra coordination time required to get the subcontractors to follow the new process.

In the end, Wall System Builders made the decision to vertically integrate the prefabricated wall system building process. They hired workers as in-house employees to build their prefabricated wall systems in their warehouse and later assemble them at the construction site. In doing so, they were able to achieve significant increases in overall productivity and profitability, while at the same time reducing the employee turnover that plagues the US residential building industry. By having the same teams work together on each of the prefabricated wall systems, they were able to develop effective routines and identify productivity enhancing procedures that crossed trade barriers.

Recently, a larger national homebuilder acquired Wall System Builders. The national builder was impressed by the productivity and profitability achieved by Wall System Builders and hoped to copy the prefabricated wall system process and diffuse it across its national operation. However, the larger builder was unwilling to integrate the different trade groups into its organization on a national scale. This meant that, from project to project, the constituency of the lumber, plumbing, mechanical, and electrical trade subcontractor teams changed. As in the Supply Chain Innovators case, this variety in constituency of subcontractors from project-to-project made it difficult for the systemic innovation to diffuse. In the end, the larger builder was unwilling to integrate the trade groups and the Wall System Builders innovation failed to diffuse across the larger organization. However, the Wall System Builders division, which continues to use integrated trade labor, remains the most profitable in the company.

Research Constructs

Based on *outcome* data on incremental and systemic innovations from third-party sources and the *process* data emerging from our two cases, a number of constructs relating to the structure of the building industry emerge. The building industry operates primarily along a project-based production paradigm. As a result of the project organization, the fragmentation of the market, and the contracts and regulations inherent in the industry (e.g., union agreements and building codes), we identified several research constructs. Below, we identify and begin to give dimension to the constructs, as well as offer propositions on how we anticipate these will impact the diffusion of systemic innovations.

Organizational Variety

This first construct refers to the change in the population of contractors from project-to-project. Both the Supply Chain Innovators case and the Wall System Builders case identified issues for diffusion related to this phenomenon. Stinchcombe (1968) described a related phenomenon as the *rate of social reconstruction*. The rate of social reconstruction refers to the rate at which groups are required to form and reform into a cohesive unit from time-to-time. If the group's constituents change from one project to the next, the rate of social reconstruction is considered high. In our research, we are less concerned with this rate than we are with the actual variety of constituents from project-to-project. Therefore, we use the term *organizational variety* to describe this construct.

We consider organizational variety high if the construct shows a tendency to use a different set of subcontractors for each trade classification from project-to-project. A long-term relationship with a particular set of subcontractors across projects would constitute a low organizational variety. Both Supply Chain Innovators and Wall System Builders reduced the organizational variety by integrating the trade subcontractors impacted by the innovation. This mechanism is also impacted by the overall fragmentation of the industry. We propose that an increase in the variety of project participants from project-to-project will decrease the rate of diffusion for a systemic innovation.

Degree of Interdependence

We propose that, as tasks become more interdependent, the rate of diffusion for a systemic innovation will decrease. Thompson (1967) introduces the concept of classifying interdependence into the literature, describing sequential, pooled, and reciprocal interdependence. Thompson introduces the concepts to illustrate how interdependence influences organizational structure. The least interdependent form is termed *pooled interdependence* to describe activities in which work does not flow between units. *Sequentially interdependent* activities are defined as those in which the output of one group is the input of another. *Reciprocal interdependence* is the most interdependent classification. It describes work in which the output of two groups must be negotiated to address sub-goal conflict.

An example of a low degree of interdependence is a manufacturing assembly line on which products are assembled sequentially. Conversely, we typically expect the building industry to exhibit a high degree of interdependence as differing trade labor groups depend on the work output of others because the input of their own work is a non-linear process (e.g., a plumber is required to complete work in several phases, each with interdependencies to other trade labor activities such as framing and electrical work). In the Wall System Builders case, we observed that the degree of interdependence is reduced when the company decides to prefabricate a wall's component subsystems within a factory environment.

Boundary Strength

Trades are grouped into different classifications, such as plumbing, mechanical, and electrical. One of the main research thrusts in market-oriented innovation studies in the building industry focuses on issues of regulation or innovation (Gann et al. 1998, Oster and Quigley 1977). We propose that the more rigid the boundary that separates the impacted trades for a given systemic innovation, the more the rate of diffusion will decrease. The rigidity of these boundaries arises from the existence of separate distribution channels, different labor training requirements, jurisdictions of labor unions, scope of services of specialty subcontractors, MasterSpec trade classifications, and path dependence.

Both cases presented in this paper describe clear delineations between trade labor groups. The Wall System Builders case, in particular, describes a resulting decrease in the turnover rate after integrating the trades. The company attributes this reduction in turnover to the fact that it allowed laborers to shift between work groups. Employees could work on the plumbing prefabrication team one week, in the field connecting the wall systems together the next week, and on the truss fabrication crew the following week. This diversity of assignment and opportunity keeps the work interesting for the employees and eliminates the boundaries separating the trades.

Span

A systemic innovation, by its very nature, will span at least one boundary between trade classifications. The number of boundaries between trades that are spanned by a given systemic innovation provides a final construct. In the case of Supply Chain Innovators, the systemic innovation spans three interfaces; the plumber-mechanical contractor interface, the plumber-electrician interface, and the electrician-mechanical contractor interface. In the case of Wall System Builders, four trade labor groups are involved. This means that six interfaces between contractors were spanned in order for the innovation to diffuse. In both cases studied, the span was reduced to zero by integrating the trade labor groups into the innovating organization. However, in the case of the large builder that acquired Wall System Builders, the span was not reduced and the innovation failed to diffuse.

Summary of Constructs

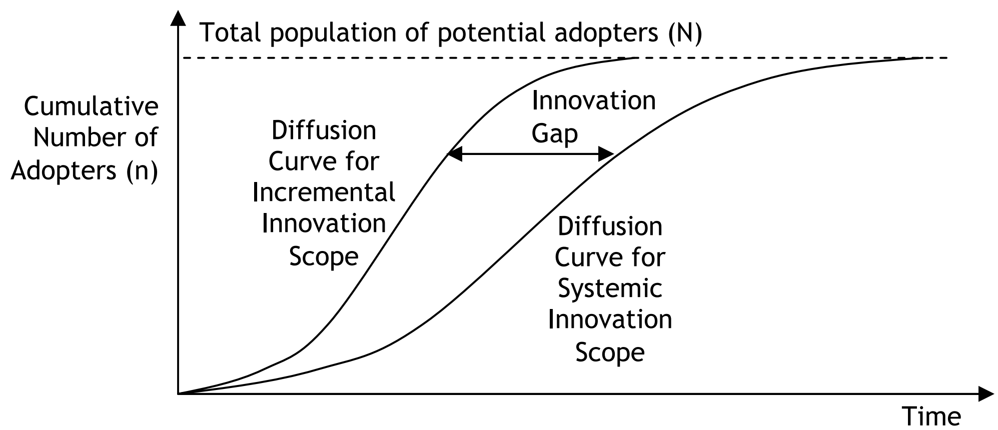
These four constructs break down the regulation, decentralization, and fragmentation structural concerns into mechanisms that can be researched and modeled. We consider a final construct, which becomes a new independent variable, called the *scope of the innovation*. We propose that the constructs described above begin to impact innovations when the scope of the innovation moves from incremental to systemic. When an incremental innovation is considered for adoption, the structural constructs will not influence diffusion. Adoption in this case can be made purely as a function of production and transaction costs for the affected firm (Williamson 1975) and cultural orientation toward innovation (Tatum 1989). However, in the case of systemic innovations, the above-defined constructs require that the set of firms involved in a given project spend extra time and cost on mutual adjustment. The magnitude of this extra coordination is a function of *organizational variety, degree of interdependence*, *boundary strength*, and *span*.

Proof-of-Concept Explanatory Model

In the research, we identify an *innovation gap* that separates the diffusion of incremental innovations from that of systemic innovations. This gap can best be understood using models for innovation diffusion. These models typically illustrate an innovation diffusing through a population by representing the cumulative number of adopters in a population over time. The resulting distribution is what is commonly described as an S-curve, or S-shaped curve. The innovation gap that we describe in this research is illustrated in Figure 2.3.

Figure 2.3 compares the cumulative number of adopters over time for innovations of varying innovation scope. The wall truss incremental innovation diffuses rapidly through the population. However, the wall truss with prefabricated components, as in the Wall Systems Builders case, diffuses much more slowly. We term the time lag between the two innovation curves as the innovation gap. We believe this gap is a function of the project-based industry structure of the US residential building industry. However, we anticipate similar effects in other project-based industries.

Figure 2.3 - Diffusion S-Curve Illustrating the "Innovation Gap"



Several different modeling frameworks exist to describe diffusion that is based on either external influence or internal influence. We will use a mixed-influence model that considers both the interactions between individuals or firms in the population (internal influence) and learning about innovations from other sources such as trade magazines (external influence). The mixed-influence model has been used to investigate the impact of location, forecast the impact of new technologies, and illustrate other diffusion-related research (Mahajan and Peterson 1985). Amendments to the mixed-influence model to describe and predict innovations in a project-based industry context have not been researched. The mixed-influence diffusion model can be described by the following equation (Lave and March 1975):

$\Delta n / \Delta t = \alpha_1 * n * (N-n) + \alpha_2 * (N-n)$ ………… [Mixed-Influence Diffusion Model]

Where; **N** = Total number of firms in the population
n = Total number of firms who have adopted at the time period
t = Time period
α_1 = Coefficient describing the internal-influence diffusion rate
α_2 = Coefficient describing the external-influence diffusion rate.

The mixed-influence model was originally introduced by Bass (1969) to describe product evolution over time. The model captures the richness of information flows in a population, but is focused on a population of individuals or firms. It does not contemplate the finer-grained mechanisms that influence the rate of adoption for different types of innovations in different organizational structures. In fact, diffusion research on organizations has been unable to achieve a strong correlation to normal distribution. However, numerous diffusion studies focused on populations of individuals have successfully correlated to the normal S-curve.

In a meta-analysis of organizational innovativeness research, Damanpour (1991) finds that diffusion can approach a normal distribution if the innovation scope and type of organization are considered. His findings suggest that the primary contingency variable should be the type of organization. In our proof-of-concept model, we add an additional coefficient, which captures the additional difficulty faced by systemic innovations in industries that use project-based types of organization:

$$\Delta n / \Delta t = \beta * \alpha_1 * n * (N-n) + \alpha_2 * (N-n) \text{............[Mixed-Influence Diffusion Model for Project-Industries]}$$

Where; **N** = Total number of firms in the population
n = Total number of firms who have adopted at the time period
t = Time period
α_1 = Coefficient describing the internal-influence diffusion rate
α_2 = Coefficient describing the external-influence diffusion rate
β = Coefficient describing the impact on internal-influence diffusion rate of project-based industry structure resulting from organizational variety, degree of interdependence, boundary strength, and span.

In cases of incremental innovations, the β coefficient is equal to 1 and has no impact on the diffusion curve. However, in cases of systemic innovations, this coefficient acts to slow the rate of diffusion. The extent of the impact on the rate of innovation diffusion is a function of the organizational variety, degree of interdependence, boundary strength, and span constructs defined in this research. This work begins to explore the finer-grained issues suggested by Damanpour (1991). This work is also a first step toward extending the Bass (1969) model to understand and predict the diffusion of systemic innovations in the project-based organizational context.

Implications for Project Managers

The traditional view of strategy suggests that firms focus on their core competences and outsource non-core business activities. This research suggests that a near-term strategy of integration may hold the key to unlocking the productivity increases that are possible through the adoption of systemic innovations. We are discussing in this paper how hierarchy-based industries were able to achieve significant productivity improvements by broadly adopting systemic innovations like enterprise resource planning, supply-chain management and component prefabrication. If project managers would like to effectively implement systemic innovations, they should address the following points.

Reduce Organizational Variety in Their Selection of Specialist Contractors

If the systemic innovation impacts the process of multiple specialists on the project, project managers should choose one contractor from each specialist group and work with them on several projects. Over time, as interorganizational routines are able to form, project managers can then begin to introduce new contractors to the bidding shortlist for each specialist firm type. However, project managers must handle this process carefully so as not to lose the productivity gains the firm has already achieved in adopting the systemic innovation.

Monitor Degree of Interdependence of the Work on the Project

Project managers must know where interdependencies lay in the project in order to understand how a systemic innovation can be adopted over the course of multiple projects. If interdependence is significant (e.g., reciprocal), project managers must pay careful attention to managing the other constructs identified in this research. If interdependence is not significant (e.g., pooled), its impact on diffusion will be less.

Reduce Boundary Strength between Specialists Impacted by the Innovation

If the systemic innovation impacts multiple specialists on your project, project managers must create an environment that develops mutual trust for those firms impacted. They should also encourage meetings and discussions between impacted firms and even possibly require project team members to work in the same space.

Monitor the Span of the Systemic Innovation

When implementing a systemic innovation, project managers must determine how many specialist firms are impacted. The more specialist firms that an innovation spans, the more difficult it will be to develop the interorganizational routines required to unlock the productivity benefits of the innovation. If there are firms that integrate the work of multiple specialist firms, such as an MEP contractor (one who performs mechanical, electrical, and plumbing work) that can be used on the project, then project managers should use them to decrease the span of the systemic innovation.

Directions for Future Research

Further research should be conducted to confirm the direction and identify the relative impact of the constructs introduced in this paper. Researchers should assess the extent to which our model addresses systemic-innovation diffusion rates in other industries. A more thorough understanding of the way in which these constructs interact to reduce the diffusion rate for systemic innovations would enable us to begin to predict the diffusion for systemic innovations in project-based industries. As firms and industries evolve into project-based forms of organization, our ability to predict these effects becomes increasingly critical. Once the explanatory model has been expanded and validated, further research should be conducted to test intervention strategies that can influence the rate of diffusion for the overall productivity-enhancing systemic innovations. This would act to counter the trending decrease in overall production efficiency identified in this paper and hopefully prevent a decrease in overall production efficiency in firms and industries that have recently adopted project-based forms of organization.

Finally, since this research takes a market-level viewpoint of innovation, researchers should complete a comparison of systemic innovation diffusion in differing market structures with differing institutional contexts. This would increase the richness of the model introduced in this paper and expand the breadth of our understanding of the diffusion of systemic innovations in project-based industries to consider variations in market context. As firms in project-based industries become increasingly global, understanding systemic change in different countries becomes a critical success factor.

Conclusions

This paper answers the call for more research on innovation in project-based industries. By taking a market-level perspective, we have shown through outcome data that, within the US residential construction industry, systemic innovations diffuse significantly more slowly than incremental innovations. We further explored the processes involved in the industry's ability to accept systemic innovations through two in-depth case studies. By triangulating evidence identified in this multi-level research, we identified a set of constructs that can explain the slower rate of diffusion for systemic innovations in project-based industries. We begin to bring dimension to these constructs and make propositions as to the impact each would have on the diffusion rate of the innovation. These constructs are then used to adapt the mixed-influence diffusion model into a proof-of-concept model. The proof-of-concept model for the diffusion of systemic innovations in project-based industries that we introduced in this paper is a first step toward explaining the disparity in the rates of incremental and systemic diffusion in project-based industries. We discussed several implications describing how project managers are impacted by systemic innovations, as well as strategies for dealing with these difficulties.

Chapter 3

Exploring the Antecedents of Boundary Object Technological Change in Interorganizational Networks

Abstract

Interorganizational networks are proliferating as a form of industrial organization. However, the processes by which networks of firms implement boundary-spanning technological changes remain poorly understood. In this paper I explore the implementation of three-dimensional computer-aided modeling tools in 26 design and construction organizations. I analyze empirical data collected over a seven month period to induce a set of antecedent constructs that enable the evolution from 'printed sets of plans' to 'virtual model' boundary objects. The findings highlight the importance of addressing interorganizational practices at the interfaces between firms in interorganizational networks when implementing boundary spanning technological change.

Introduction

The ability of organizations to sustain competitive advantage rests in part on their successful implementation of new technologies. Over the past several decades information systems have provided a steady stream of technological changes for organizations to employ to keep pace with competitors. Many of these changes have taken the form of integrated information systems that some researchers contend require a fundamental reexamination of the concepts of markets and hierarchies (Malone et al. 1987). Within hierarchically organized firms, enterprise-wide integrated information system implementation has proven to be wrought with unforeseen hazards (Block 1983, Davenport 1998, Sumner 2000). Block (1983) identified a dozen categories of determinants to explain enterprise-wide information system implementation failures. Despite the potential for failure, the successful implementation of integrated information systems provides a rich source for sustained competitive advantage in firms (Mata et al. 1995, Powell and Dent-Micallef 1997).

Building on some of the same capabilities of integrated information systems, interorganizational networks have increasingly replaced traditional vertically-integrated hierarchies over the past several decades (Barley et al. 1992, Pekar and Allio 1994). Interorganizational networks were first discovered in the Massachusetts house building industry by Eccles (1981). Eccles described these networks as *quasifirms* where house building contractors maintain long-term contractual relationships with subcontractors even if those subcontractors did not provide the lowest market price to perform their work. He described the *quasifirm* form of organization as existing between the traditional markets and hierarchies outlined in transaction cost economics by Williamson (1975). Williamson (1985) later supplemented his transaction cost framework with the concept of *hybrid* organizations as an intermediate form of organization existing between markets and hierarchies.

Since these early studies of interorganizational networks, research has extended beyond economic exchange arguments to consider networks as a new, independent form of organization (Miles and Snow 1986, Powell 1987, 1990). Researchers of the network form of organization seek to understand how interactions between organizations are governed (Granovetter 1992, Jones et al. 1997, Stinchcombe 1985), how firms select network partners (Beckman et al. 2004, Galaskiewicz 1985, Pekar and Allio 1994), the stability of interactions between networked firms (Gulati 1995, Powell et al. 2005), and how knowledge flows across networked firms (Appleyard 1996, Uzzi and Gillespie 2002). Although research on interorganizational networks investigates the relational aspects of networks and the knowledge exchanged, interorganizational researchers have largely ignored the interstitial objects that connect the work and provide a vehicle for exchanges of knowledge between disparate organizations in networks.

The growth and proliferation of research on interorganizational networks led information systems researchers to investigate the implementation of these systems across organizational boundaries in networks. Numerous researchers found the implementation of interorganizational information systems to be a source of competitive advantage in interorganizational networks (Bakos 1997, Bakos and Treacy 1986, Cash and Konsynski 1985, Johnston and Vitale 1988). Cash and Konsynski (1985) proposed that information systems can enable the redrawing of organizational boundaries. Some researchers proposed that interorganizational information systems themselves provide the integrating mechanisms to connect organizations into networks (Argyres 1999, Johnston and Lawrence 1988, Venkatraman and Zaheer 1991).

The linkage between integrated technologies and interorganizational information systems led to a thread of research pursuing the notion that competitive advantage lies in reducing the rigidity of the boundaries of organizations, even to the point of organizations becoming *boundaryless* (Devanna and Tichy 1990). However, more recent research finds that boundary activities may actually increase in significance in "*boundaryless"* organizations (Cross et al. 2000, Hirschhorn and Gilmore 1992). Though the formal boundaries may appear to be reducing in importance, integrated information systems can become increasingly important intermediate boundary objects to link the work and enable the exchange of knowledge between disparate organizations in networks (Briers and Chua 2001, Pawlowski and Robey 2004).

Star and Griesmer (1989) introduced the concept of *boundary objects* to describe objects that inhabit intersecting social worlds while at the same time satisfying the information requirements for each separate group. Interorganizational information systems are one example of a boundary object that connects the work of different occupational fields (Levina and Vaast 2005, Pawlowski and Robey 2004). Other examples of boundary objects include prototypes (Carlile 2002, D'Adderio 2001), sketches (Henderson 1991, 1999), project management tools (Sapsed and Salter 2004), or designs (Bechky 2003). These boundary objects play a mediating role to connect the disparate social worlds of the designers and the builders of those designs while at the same time enabling individuals from both groups to conduct their work.

In Henderson's (1999) ethnographic study of the evolution from paper-based to computer-aided drafting among designers we learn that technological change in boundary objects can have a significant impact in the structuring of work and status of individuals within design firms. This study of implementing technological change in boundary objects provides a rich understanding of the difficulties a single firm faces.

However, it offers little direction to navigate technological changes in boundary objects that span organizational boundaries. If technological change in boundary objects can erode current patterns of work within a firm, what impact can it have on interdependent firms in interorganizational networks? Though researchers have explored the issues associated with interorganizational information system boundary objects in networks (Briers and Chua 2001, Pawlowski and Robey 2004), there is little guidance about how a network of firms would go about implementing technological changes of this kind. If the successful implementation of interorganizational systems is critical to sustaining competitive advantage (Bakos 1997, Bakos and Treacy 1986, Cash and Konsynski 1985, Johnston and Vitale 1988), then firms involved in interorganizational networks must understand how to implement technological change in boundary objects to remain competitive.

This paper explores the question of *how firms in interorganizational networks implement technological change in boundary objects*. Building on previous work on the evolution from paper-based to computer-aided drafting in design firms (Argyres 1999, Henderson 1991, 1999; Manske and Wolf 1989, Robertson and Allen 1992, Salzman 1989) and particularly on those studies exploring boundary object change (Henderson 1991, 1999), I explore the recent evolution from two-dimensional (2D) computer-aided drafting (CAD) to 3D CAD in design and construction networks. The boundary object exchanged between designers and contractors remained stable in the evolution from paper-based drafting to 2D CAD. Designers continued to share designs with the contractor as a set of paper-based line drawings. However, with the evolution from 2D CAD to 3D CAD, the disparate social worlds of design and construction began to be brought together to co-create a virtual model of the planned structure.

Research Setting and Methodology

I employed a qualitative approach (Eisenhardt 1989, Glaser and Strauss 1967, Strauss and Corbin 1990, Yin 1989) to gather and analyze the experiences and perspectives of designers and contractors on their successful implementation of 3D CAD tools. I asked informants to describe two recent projects; one prior to the implementation of the design tool, and a similar project after the tool had been implemented where the usage of the tool had been successful. I then asked the informants to elaborate on the aspects of the implementation that made it successful. I also spent several weeks observing the implementation of 3D CAD within and across design and construction organizations. From this data I developed a grounded understanding of how firms in interorganizational networks successfully implement 3D CAD software and was able to induce a set of antecedent constructs relating to successful boundary object technological change in design and construction networks.

Sample and Data Collection

Researchers suggest that qualitative case research should employ multiple data collection methods in order to increase the validity of the constructs identified (Eisenhardt 1989). In this study, I employ multiple data collection methods; including, ethnographic interviews, direct observation, and review of primary and secondary documentation. Researchers recommend using multiple case studies to further increase internal construct validity (Eisenhardt 1991). To accomplish this, I replicated the data collection effort across 26 different organizations in this research investigation. During the course of this research I spent several weeks as an observer of six 3D CAD projects involving both design and construction organizations in the United States.

By triangulating the findings across these different cases and data collection methods I strengthen the validity of the findings (Eisenhardt 1989). The data collection effort took place over a seven month period from June 2004 through December 2004. Of the firms investigated in this project, 13 were construction firms and 13 were design firms. In order to select firms for inclusion in this study, I specifically approached companies that had successfully implemented a 3D CAD tool. Therefore, the organizations in the study were selected for their ability to provide analytic generalization, they were not randomly sampled (Yin 1989).

Research Context

From 2D CAD to 3D CAD

Argyres (1999) found that the implementation of 3D CAD among the firms that designed and developed the B-2 "Stealth" bomber both enhanced coordination and enabled the creation of an entirely new kind aircraft. He postulated that 3D CAD could be a source for competitive advantage in strategic alliances when compared to earlier advances in CAD. According to one 3D CAD tool provider, this technology will have similar coordination benefits in the design and construction industry. They describe the development of a virtual model of a building with 3D CAD as follows:

> "...a computer model database of building design information, which may also contain information about the building's construction, management, operations, and maintenance. From this central database, different views of the information can be generated automatically, views which correspond to traditional building design documents, like plans, sections, elevations, quantity take-offs, door and window schedules, 3D model views, renderings and animations. Because these resulting documents can be derived from the same database, they are all coordinated and accurate." (Barron 2003, p. 2)

Harty (2005) documented how the adoption of 3D CAD on a large design and construction project led to coordination difficulties between firms. Whereas this technology creates an opportunity to improve the coordination and accuracy of the design and construction model (Barron 2003), it can also create coordination difficulties across firms in design and construction networks. Mitropoulos and Tatum (1999) found that the adoption of 3D CAD can be hindered by decision processes within construction organizations. Whyte and her colleagues (1999) determined that 3D CAD software is being adopted more slowly than its predecessor 2D CAD. Harty's (2005) study of the adoption of 3D CAD is instructive in that it suggests that social and organizational contexts need to be taken into consideration to understand issues associated with the adoption of this technology. He pointed out how the technology had spillover effects beyond the adopting firm (Harty, 2005). However, the process by which design and construction firms in interorganizational networks address these spillover effects and successfully implement boundary object technological change remains poorly understood.

An increasing number of researchers are exploring the use of 3D CAD tools to integrate processes not possible with 2D CAD. Researchers explore the use of 3D CAD to integrate and improve the scheduling of construction activities (Songer et al. 2001), the estimation of costs (Staub-French et al. 2003), the identification of time-space conflicts in production (Akinci et al. 2002), and the visualization of the construction process (McKinney and Fischer 1998). The realization of the increased functionality and productivity associated with these tools requires firms first to successfully implement 3D CAD tools.

Numerous studies point to the significant changes 2D CAD introduced within organizations as they evolved from paper-based methods. Manske and Wolf (1989) identified the emergence of new roles to complement new skill requirements within design organizations that implemented 2D CAD. Salzman (1989) also identified how the skill requirements of employees in design firms changed as a result of implementing 2D CAD. Robertson and Allen (1992) and Henderson (1999) both describe how work was restructured within organizations evolving from drafting to 2D CAD. Henderson (1999) further described in her ethnographic account of the implementation of 2D CAD how the relations between employees changed. None of these studies, however, identified changes occurring across organizational boundaries.

With both paper-based drafting and 2D CAD, building information was typically exchanged between firms in the form of a printed set of plans. The plans themselves then became the visual representations upon which discussions within and between design and construction organizations were based. This boundary object (the printed set of plans) between designers and contractors is central for coordination and provides the locus for elaborating and resolving conflicts (Henderson 1999). The plans span the separate social worlds of designers and contractors and satisfy the information requirements of each, meeting Star and Greismer's (1989) definition for a boundary object. In order for 3D CAD to achieve the potential prescribed by numerous tool-based investigations (Akinci et al. 2002, McKinney and Fischer 1998, Songer et al. 2001, Staub-French et al. 2003), the boundary object must evolve significantly from a 'printed set of plans' to a 'virtual model'. The adoption of 3D CAD differs from the earlier evolution to 2D CAD technology because it requires designers and contractors to work together across firm boundaries to co-create the virtual building model.

Figure 3.1 illustrates some of the interactions between the occupational fields of design and construction related to the 'printed set of plans' boundary object. Architectural designers create conceptual designs either through sketching or the development of computer-aided designs in 2D CAD. This printed set of conceptual design plans becomes the initial boundary object which is shared with engineering designers to analyze and create structural designs which are then reviewed for coordination by a set of specialized trade contractors. The architectural designer considers the implications of the structural design, refines the original conceptual design, and creates a detailed design which is shared with the general contractor as a printed set of plans. The general contractor reviews this printed set of plans for constructability and provides requests for information to advise the architectural designer of any suggested or required changes. This process of interaction with the printed set of plans goes on throughout the design and construction process. In some cases where owners require it, general contractors and trade contractors may even edit (or "redline") the set of plans to reflect what was actually constructed.

Figure 3.1 - Paper-based 'Set of Plans' Boundary Object Evolution Enacted through Designer and Contractor Interactions

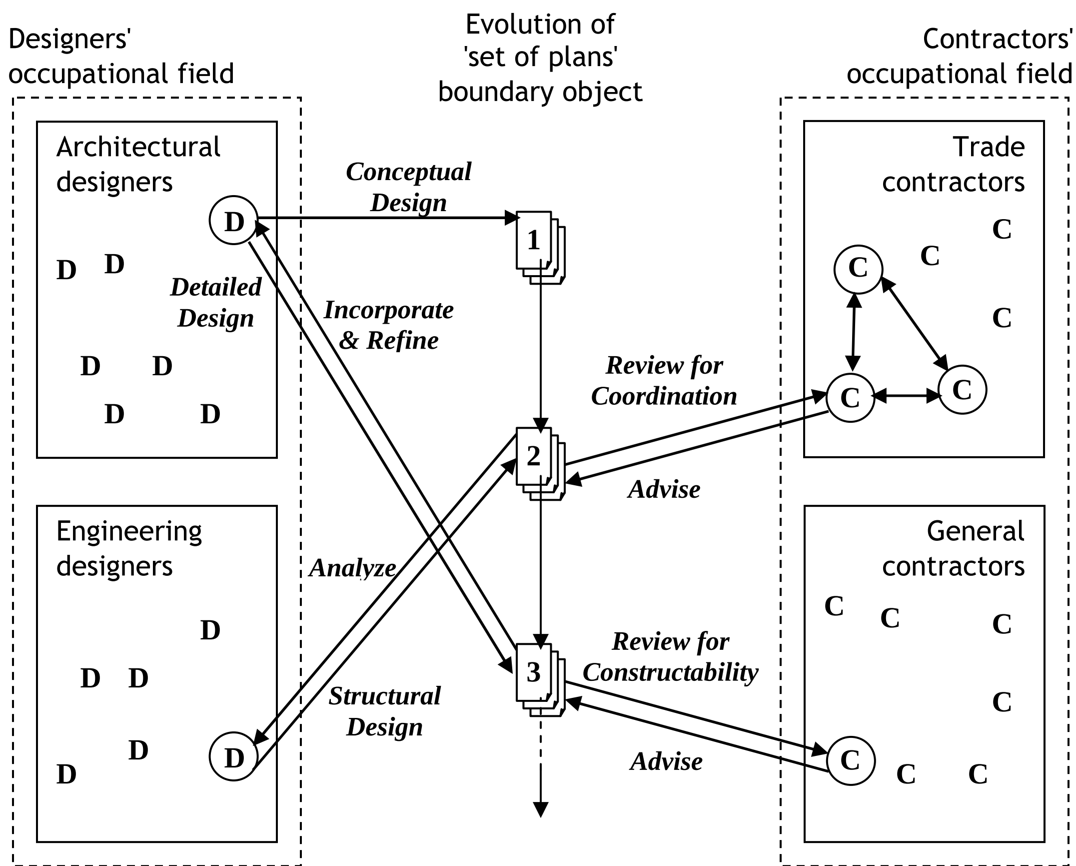
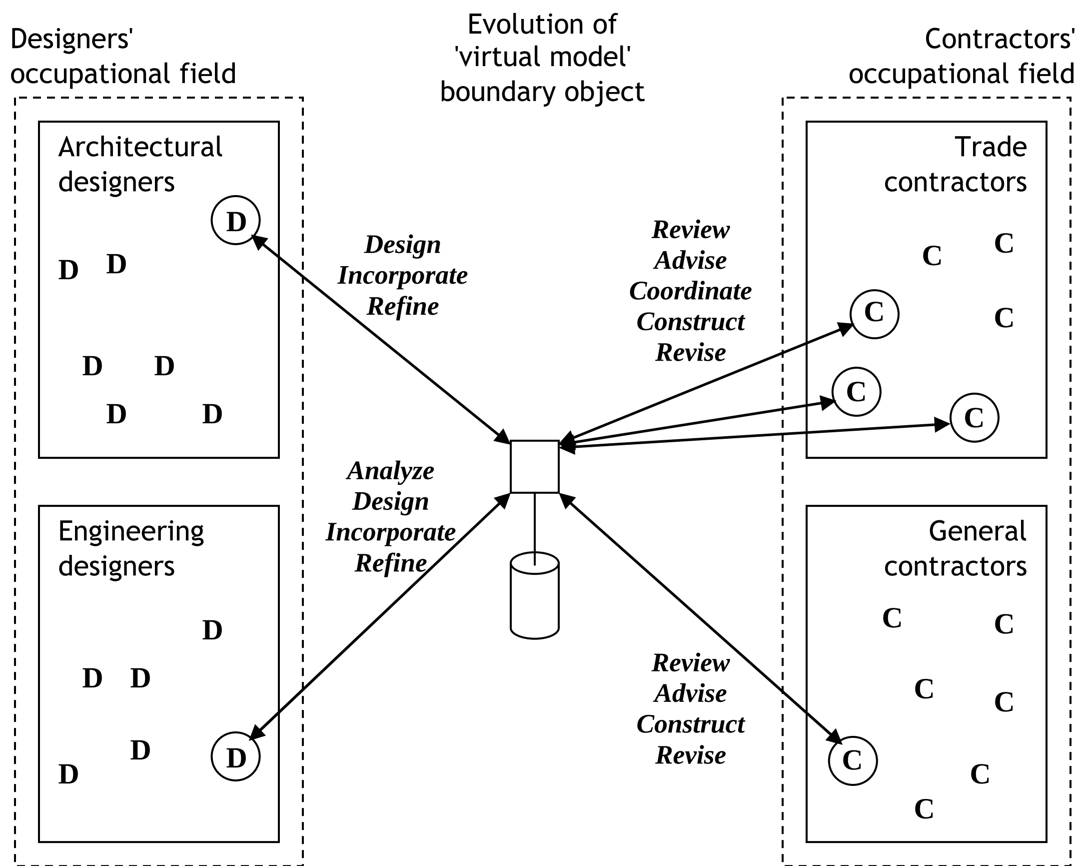


Figure 3.2 illustrates how design and construction occupational fields interact with the 'virtual model' boundary object. With 3D CAD, organizations from the separate social worlds of design and construction are brought together to co-create a 'virtual model' for a building. Design and construction organizations have some flexibility in the extent to which they co-create virtual models. They can create the virtual model internal to their own organization, they can co-create the model with other designers or contractors on a building project, or they can move beyond sharing with project partners and co-create the model with material suppliers. In Figure 3.3, we describe the process by which designers and contractors co-create a virtual model boundary object.

Figure 3.2 - 'Virtual Model' Boundary Object Evolution Enacted through Designer and Contractor Interactions



Where the development and exchange of a 'printed set of plans' was based on work done within a design or construction firm, the co-creation of a 'virtual model' requires overlapping participation. Some designers described this as "bringing the contractor on board early." It is in these interactive sessions represented in Figure 3.2 where designers design, analyze, incorporate and refine while contractors review, advise and coordinate. The fact that designers and contractors come from different social worlds with different interpretations of 'printed sets of plans' becomes evident in these sessions. Designers described surprises in this co-creation environment as "we aren't normally thinking about how wall lines interact with the ceiling" while "the guy with building experiences is thinking 'what kind of wall is that?'." This tighter interaction created some problems initially in the co-creation of the virtual model as the reciprocally interdependent work required mutual adjustments between the firms involved (Thompson 1967). One contractor stated that "there are deep-seated issues with getting people from different disciplines to talk to each other and get along."

3D CAD uses virtual objects to represent various elements of a building. When a set of printed plans were shared sequentially between organizations, each disparate organization could describe the elements as they wished. When a designer or a contractor viewed a set of printed plans illustrating a glass exterior of a building, the contractor might describe it as a curtain wall while an architect might describe it as a facade. However, when individuals from the separate worlds of design and construction are brought together to co-create this same glass exterior collaboratively, differences in naming conventions and the requirements for representing different features of the glass exterior can lead to coordination difficulties and conflicts.

Design and Construction Organizations

I investigate the implementation of 3D CAD software in 26 design and construction organizations. Design and construction networks have been the focus of a number of recent innovation studies pointing out issues associated with interdependent, networked nature of this industry and its work (Barlow 2000, Gann and Salter 2000, Miozzo and Dewick 2002, Salter and Gann 2003, Taylor and Levitt 2004). Each of these studies identified learning in the project-based design and construction networks as an inhibitor to change. None of these studies, however, investigated technological change in the boundary objects that connect the disparate worlds of design and construction. In this paper I investigate the technological change from the 'printed set of plans' boundary object that connect design and construction organizations to the co-creation of a 'virtual model' in order to better understand how change occurs in these networks.

The design and construction firms included in this study were not selected based on the implementation of a specific 3D CAD tool. I was less interested in the specific tool and more interested in identifying trends across different types of tools that led to successful implementation. I included only firms that had completed at least one project using 3D CAD software. Of the firms included in the study, 13 had completed between one and five 3D CAD projects, 9 had completed between six and twenty-five projects, and 4 had completed more than twenty-six projects. In addition to data about the specialization of each firm (designer or contractor), I tracked the location of the company headquarters (US, Europe or Asia) and the scale of that firm's operations (local, national or international). Regarding each firm's technology implementation, I tracked the number of 3D CAD projects they had completed (1-5, 6-25, or more than 26 projects).

I also tracked the degree to which the 3D CAD work was co-created with other firms. Four of the firms in the sample were using 3D CAD successfully within their firm without co-creating the 'virtual model' with other firms. Twelve of the firms in the sample co-created the 3D CAD model with another specialist firm on the project (e.g., designers working together with contractors). Ten of the firms in the sample were actually moving beyond co-creating the model between design and construction firms. These firms extended their cooperation in the development of the 'virtual model' of the building with material suppliers (e.g., structural steel fabricators and window manufacturers) who would fabricate elements of the building directly from the model. It was not my original intention or expectation to observe co-creation of 'virtual model' artifacts at this level. However, it is instructive to understand the extent of the propagation of this boundary object technological change. Table 3.1 provides details about the 26 firms included in the study.

Table 3.1 - Details of Design and Construction Organizations Investigated

Firm	Specialization	Location of head-quarters	Scale of operations	Number of 3D CAD projects completed	Extent to which 3D CAD virtual models were co-created
1	Contractor	US	International	6-25	Into Supply Chain
2	Contractor	Europe	International	6-25	Across Project
3	Contractor	US	National	1-5	Across Project
4	Contractor	Asia	International	1-5	Within Firm
5	Contractor	US	International	>26	Into Supply Chain
6	Contractor	US	National	6-25	Across Project
7	Contractor	Europe	International	>26	Into Supply Chain
8	Contractor	Europe	National	6-25	Across Project
9	Contractor	Europe	International	6-25	Into Supply Chain
10	Contractor	Europe	International	>26	Into Supply Chain
11	Contractor	US	Local	1-5	Into Supply Chain
12	Contractor	US	Local	1-5	Across Project
13	Contractor	US	Local	1-5	Across Project
14	Designer	US	National	6-25	Into Supply Chain
15	Designer	Europe	National	6-25	Into Supply Chain
16	Designer	US	Local	1-5	Across Project
17	Designer	US	National	1-5	Within Firm
18	Designer	US	National	1-5	Across Project
19	Designer	US	International	6-25	Within Firm
20	Designer	Europe	International	1-5	Within Firm
21	Designer	US	International	1-5	Across Project
22	Designer	US	International	>26	Into Supply Chain
23	Designer	US	International	1-5	Across Project
24	Designer	Europe	International	1-5	Across Project
25	Designer	US	International	1-5	Across Project
26	Designer	Asia	International	6-25	Into Supply Chain

Data was collected via interviews of approximately three hours in duration. I collected approximately 90 hours of interview data during the course of the data collection. An interview protocol was used during the interviews to make sure the interview covered the basic discussion points. However, the protocol was designed to encourage the interviewees to speak at length, in their own words, about their experiences before and during the successful implementation of 3D CAD in the context of specific projects.

In addition to interview discussions, direct observations of six 3D CAD projects involving designers and contractors were made over a period of several weeks. I was invited to attend project and company meetings, to visit project sites, to observe the interaction between participants on the projects freely, and to discuss my observations with my informants within the design and construction organizations involved. I took extensive notes during this process and took digital photographs for use in my data analysis. Interview discussions and noted observations were recorded in a numbered set of field research notebooks. Interview discussions were also recorded using a digital voice recorder.

Whenever possible, I requested hard copies of materials discussed during interview discussions and observations. Data collected included contract documents, process flow diagrams, project schedules, design models, bills of materials, project decision schedules, animations of design models, and any other information that might lend insight into the successful internal and interorganizational implementation of 3D CAD. This primary documentation was attached to my field notebooks and often elucidated concepts that were not entirely clear when reviewing the notes from an interview or observation. Overall, I was able to manage the reliability of the findings by keeping an indexed, organized database of my field notebooks, audio interview files, photographs, and documents collected.

Content Analysis

Because I did not use a structured interview, interviewees were able to discuss topics spontaneously that they felt were important regarding their implementation of 3D CAD software. Interview quotes were only included in the qualitative content analysis if they dealt specifically with the implementation of 3D CAD software. Quotations varied from short quotes to longer, multi-sentence discussions. The idea was to encapsulate a complete thought that could be compared and contrasted with other quotations to formulate constructs.

I performed a line-by-line microanalysis of this data (Strauss and Corbin 1990). From the microanalysis process, 282 anecdotal quotes relating to successful 3D CAD implementation emerged from the raw data. All quotations identified in the data that were relevant to implementing 3D CAD were coded into a database. The quotes were roughly equally distributed between designers (n=158 quotations) and contractors (n=124 quotations). These quotes were then analyzed using the constant comparative method (Glaser and Strauss 1967) to develop and refine set of 27 conceptual categories. I then systematically analyzed the 282 relevant implementation anecdotes to identify patterns in an axial coding process (Strauss and Corbin 1990).

Implementing Boundary Object Technological Change

The content analysis revealed 27 unique conceptual categories that relate to successful 3D CAD software implementation in design and construction networks. Of these antecedents, 14 account for over 85% of the coded occurrences analyzed in the study. For parsimony I will only include the antecedent constructs that represent 85% of the collected data in the following discussion. Researchers suggest focusing on constructs that represent 80% to 90% of the data to identify key variables (Dunteman 1989). In Table 3.2 below, I list the 14 key antecedent constructs of successful boundary object technology implementation. For each construct I include the frequency of quotations for designers, for contractors, and for all firms in the study.

Table 3.2 - Antecedents of Successful 3D CAD Implementation Cross-classified by Specialist Firm Type

	Specialist firm type		
Antecedent	Relative frequency of designer responses (n=158)	Relative frequency of contractor responses (n=124)	Relative frequency of all firm responses (n=282)
Redistribute work among firms	14.6	12.1	13.5
Increase collaboration between firms	9.5	8.1	8.9
Develop partnerships between firms	7.6	7.3	7.5
Develop standards for interaction	6.3	8.1	7.1
Experiment with 3D CAD	5.1	8.1	6.4
Understand shared interests among firms	6.3	6.5	6.4
Develop system understanding of project	5.7	5.7	5.7
Address interoperability of technology	6.3	4.0	5.3
Work with firms using same software	3.8	6.5	5.0
Obtain sufficient 3D CAD training	4.4	4.8	4.6
Address issues of liability	6.3	1.6	4.3
Address contractual constraints	5.7	1.6	3.9
Work with an external change agent	4.4	2.4	3.6
Cross-pollinate ideas across firms	0.6	6.5	3.2
Miscellaneous remaining antecedents which when combined account for less than 15% of responses for all firms	13.3	16.9	14.9
Column Totals	100	100	100

Upon closer examination of the constructs presented in Table 3.2, I observe that there is both strong agreement and some variance in the frequency of responses for each key antecedent when comparing the implementation perspectives of designers to those of contractors. This is not surprising given the separate occupational fields and social worlds from which designers and contractors originate. By comparing relative frequencies across the design and construction functions we can discern more distinctly the separation of the antecedents across design and construction implementation perspectives. The difference between the relative frequencies for designers and contractors for each key antecedent are tabulated in Table 3.3. For each antecedent the number of standard deviations from the mean of the variances in the frequencies is listed.

Table 3.3 - Cross-comparison of Relative Frequencies for Key Antecedents across Designers and Contractors

Key antecedents	Relative frequency for designers minus relative frequency for contractors (in percent)	# of standard deviations from mean of variances
Address issues of liability	+4.7	1 to 2
Address contractual constraints	+4.1	
Redistribute work among firms	+2.5	0 to 1
Address interoperability of technology	+2.3	
Work with an external change agent	+2.0	
Increase collaboration between firms	+1.4	
Develop partnerships between firms	+0.3	
Develop system understanding of project	+0.1	
Understand shared interests among firms	-0.1	
Obtain sufficient 3D CAD training	-0.4	
Develop standards for interaction	-1.7	
Work with firms using same software	-2.7	1 to 2
Experiment with 3D CAD	-3.0	
Cross-pollinate ideas across firms	-5.8	2 to 3
Mean of variances	+0.3	
Standard Deviation	2.9	

Designer's Perspective of 3D CAD Implementation

It is more important for designers than contractors to *address issues of liability* and to *address contractual constraints* (1 to 2 standard deviations from mean variances as described in Table 3.3). When the printed plans were the boundary object connecting designers and contractors, the plans contained a notation that indicated they were not to scale. With the co-creation of a virtual model boundary object, it is no longer feasible to create designs that are not to scale. Contractors must be able to plan production and fabrication from the virtual model and, as such, dimensions and the connections between objects in the building information model must be precise. This introduces new liability considerations for design organizations when the contractors are working under traditional lump-sum construction contracts. With printed plans that are not to scale, contractors make field adjustments to accommodate precise connections between building objects. With a virtual model, however, if a dimension is imprecise and an element does not connect to a building properly during construction, then a contractor can claim that this is the fault of the designer. Designers explained that:

> "in design professional's drawings, the dimensions are not exact, a contractor interprets these and creates shop drawings with exact dimensions … if a dimension is wrong it's the contractor's fault, if derived from the 3D CAD model the architect would be responsible"

This comment was echoed by a contractor who described why, in some instances, they recreate the 3D CAD model even when it is furnished by the architect. He described this concern over liability as follows, "if we get a 3D CAD model from an architect there may be mistakes since the architect doesn't guarantee that the model is correct." Surprisingly, issues of liability had not been addressed explicitly in contracts. Designers described 3D CAD technology as being sufficiently new that it had not yet been contemplated by the legal profession. Firms that successfully implemented 3D CAD within their design and construction network made only minor modifications to their contract documents. Interestingly, in some cases the virtual model co-created by the designers and the contractors became a component of the contract. One designer describes the virtual model becoming part of the contract documents as follows:

> "in our last project the 3D CAD model became part of the contract documents … the legal side of this is not too complex but there is a fundamental distrust of digital data, you have to tell the structural steel fabricator that the data is accurate"

More generally, designers spoke of the scope of contract changes as needing only to "add a paragraph or two on a case-by-case basis" or "we only added a front page to the contract." Although the virtual model is co-created across designers and contractors, it takes its initial form in design organizations. One of the stated benefits of 3D CAD over 2D CAD is more accuracy (Barron 2003). However, achieving that accuracy requires design firms to *address contractual constraints* and *address issues of liability*.

Contractor's Perspective of 3D CAD Implementation

In contrast to designers, successful implementation of 3D CAD in contractor organizations focused on working with designers to *cross-pollinate ideas across firms* (2 to 3 standard deviations from mean of variances as described in Table 3.3). The idea that design and construction firms would cross-pollinate ideas with 3D CAD would seem to indicate that this level of interaction did not exist in the past. Unlike the exchange of a set of printed plans with paper-based drafting and 2D CAD, the co-creation of a virtual model requires disparate design and construction organizations to work together more closely. In doing so, construction firms are able to more clearly articulate their knowledge of constructability issues and get changes into the model that otherwise would have had to be worked out in the field during construction or later "with a jackhammer."

According to contractors, the co-creation of a virtual model enabled firms to "swap roles to understand what is important to other specialists" and "by putting teams together with the model we're able to get unintended benefits." One firm described that they were able to gain an extra floor in the building due to cross-pollination of constructability ideas in design:

> "normally this building would be 15 foot floor-to-floor height, we gained a floor in the building by achieving a 14 foot floor-to-floor height"

Contractors also expressed the need to *experiment with 3D CAD* more frequently than designers (1 to 2 standard deviations from mean of variances as described in Table 3.3) when implementing 3D CAD. Contractors have been described by researchers as having difficulties adopting new technologies, in particular 3D CAD (Mitropoulos and Tatum 1999, Whyte et al. 1999). In contrast, designers have been described as being creative and engaged in experimenting with new ideas (Henderson 1999, Salter and Gann 2003). In order to successfully implement 3D CAD, contractors need to develop a more experimental attitude. One contractor described that "one big hurdle for 3D CAD is inertia—we've always done it this way, we're a conservative industry." Another contractor described an initial passive resistance to 3D CAD as "a lot of saying 'yes' but nodding 'no'... not in my back yard." Some contractors described a process involving as much as six months of experimentation with 3D CAD, hiring and replacing numerous CAD managers, and conducting a number of team building exercises before achieving successful implementation.

A practical concern for contractors *vis-a-vis* designers in implementing 3D CAD was the need to *work with firms using the same software* (1 to 2 standard deviations from mean variances as described in Table 3.3). When a designer implements 3D CAD, their firm can build a virtual model with their own internal resources or co-create the virtual model with the contractor. However, for a contractor to implement 3D CAD successfully it requires the initial building information model input from the designer. Otherwise, the contractor has to recreate the entire design. In the words of one contractor "even if I can use 3D CAD, if the designer can't use it, why bother." Another contractor describes their experience on a recent project where their partners did not use 3D CAD as follows:

> "on our last project all our partners were still using 2D CAD so we had to constantly go from 3D to 2D to communicate files rather than slicing and dicing into layers"

In contrast with designers, in order for contractors to successfully implement 3D CAD contractors must take advantage of opportunities to *cross-pollinate ideas across firms* about constructability, they must deal with inertia against change in their occupational field to *experiment with 3D CAD*, and finally they must identify and *work with firms using the same 3D CAD software*. Construction firms that address these three areas are able to successfully implement technological change in the boundary object that connects their work to design organizations. In doing so, construction firms identified tremendous increases in productivity. One firm described how on their first implementation of 3D CAD they were able to reduce the number of revisions from a running average of 30-35% to 10%. And the accuracy continued to improve with the move from using a set of printed plans developed by a designer to co-creating a virtual model with the designer.

Shared Perspectives on 3D CAD Implementation

In addition to the specific perspectives of designers and contractors, there were a set of shared perspectives common across both occupational fields. The antecedent constructs that are of similar importance (from 0 to 1 standard deviations from mean of variances as described in Table 3.3) to both designers and contractors can be classified into three broad thematic areas; firm and technology interfaces, changes in the scope and pattern of work across firms, and change management. I will discuss the findings in each of these areas in the following three sections.

Firm and Technology Interfaces

Designers and contractors both reported that addressing interfaces between their respective organizations and 3D CAD technologies was critical to successfully implementing 3D CAD tools. This area contains the largest relative frequency of citations and includes the following antecedent constructs; *increase collaboration between firms*, *develop partnerships between firms*, *understand shared interest among firms*, and *address interoperability of technology*. It is critical for design and construction organizations to work together to improve organizational interfaces through collaboration, partnerships, understanding shared interests and to improve technology interfaces.

At the organizational interface between designers and contractors, networks that *increase collaboration between firms* were generally more effective at implementing 3D CAD across organizations. One contractor describes this collaboration as a way to both eliminate conflicts and to identify opportunities for improving the design. The contractor described how with improved collaboration the designer "gets input from different people" and in doing so "he immediately sees interferences especially across disciplines like a pipe going through a beam." A contractor also described how improved collaboration with the designer actually created opportunities to increase the density of a building. The contractor indicated that "in a few cases (the designer) identified spaces where we can route ducts that would normally be for another system." Attaining the benefits of *cross-pollinating ideas across firms* described earlier is contingent upon *increasing collaboration between firms* in the design and construction network.

Some firms in the sample who successfully implemented 3D CAD tools progressed beyond collaboration to *develop partnerships between firms* in the network. An architect described how "when you have ongoing relationships you can leverage learning to work together with (3D CAD) over and over again." The architect described this learning that comes through partnerships as "a function of percolation." A contractor also described the use of partnerships in successful 3D software implementation across designers and contractors in terms of learning. The contractor described that "establishing more partnerships and not working with different firms from project to project is important as it takes time to learn to work together with a new technology and develop a common strategy." Design and construction firms that address interactions through collaboration and partnership are able to strengthen interorganizational learning associated with the new technology.

A smaller group of firms in the study advanced beyond collaboration and partnership and explored how 3D CAD could be implemented to improve processes beyond their own firm. In doing so, these firms *understood shared interests among firms* in their network. With the limited meaningful interaction available using a printed set of plans, design and construction firms had difficulty understanding each others' interests. If a designer does not consider a contractor's interests and vice-versa, the implementation of 3D CAD or other technologies in the design or construction organization can be counterproductive to the other due to interdependencies in the work. One contractor interviewed described how a sharing of interests is a step beyond partnership. They described that:

> "twice per year we have a meeting to discuss how we can make our partnerships deeper and more profitable for both partners … partnership is not just an empty phrase, we want each other to succeed."

An architect in the study made a similar claim, in this case stressing how improving the interactions between designers and contractors is more important than issues related to technology implementation. The architect pointed out that:

> "developing cooperative relationships is more important than the technology … participants need to sit around the same table and realize their shared interests."

Though there were different degrees to which firms in the sample addressed organizational interfaces between designers and contractors, firms that successfully implemented 3D CAD were observed to improve collaboration, develop partnerships, or move beyond partnership to understanding each other's shared interests. This highlights the fact that 3D CAD software impacts both designers and contractors, even if they adopt the technology separately. In addition to addressing organizational interfaces, both design and construction firms must *address the interoperability of technology* at the technological interface between their firms. In other words, in order to co-create a virtual model, the 3D CAD software in both firms must be capable of opening and editing the electronic building information model. One contractor described a recent project where all the participating firms were using 3D CAD but that "there were interoperability problems (due to) 20 different file formats." Generally, firms addressed the technology interface between organizations by requiring their partners to use the same 3D CAD software of the same version. One designer describes how they successfully implement 3D CAD across their design and construction network as follows:

> "all our (partners) have to be on IFC compliant software of the same version … it's in the contract" [Note: 'IFC' refers to Industry Foundation Classes, a content standard for 3D CAD objects in the building industry]

Achieving the potential of 3D CAD requires firms to share and co-produce electronic files of buildings. To do so, interfaces between firms and technologies need to be addressed to accommodate the development and learning of interorganizational routines. The deeper the relationship that bridges the interactions between designers and contractors, the more likely firms are to develop novel solutions to design and construction problems that benefit both partner firms.

Change in the Scope and Pattern of Work across Firms

In the previous section I spoke of the development and learning of interorganizational routines and how addressing the interfaces between organizations and technologies in networks can help to facilitate these. In this section I will describe more specifically how the scope and pattern of work across firms changed for design and construction firms that successfully implemented 3D CAD software. As one architect described, "the big change with (3D CAD) is not technological, it's changing the process." Design and construction firms that successfully implemented 3D CAD *redistributed work among firms*, *developed standards for interaction*, and *developed a system understanding of the project*.

The key antecedent of *redistributing work among firms* in design and construction networks was the most cited construct in the study (responses relating to this construct alone account for 10.3% of all responses). Both designers and contractors described how the use of 3D CAD software shifted some of the work traditionally done by contractors and material suppliers into the domain of the designer. With the development of a virtual model, designers must provide more detailed and more accurate models. Contractors must also change their work practices to successfully accommodate 3D CAD into their work. One contractor described how "in order for (3D CAD) to work, the flow of work had to change … we're relying more and more on 3D stations in the field." The pattern of work is changing as a result of technological change in the boundary object connecting the work of designers and contractors. Work that used to be completed separately in company offices is now being shifted into the field where designers and contractors can co-create virtual models together more effectively.

A contractor describes the shift in work from a supplier to a designer in the context of a successful 3D CAD implementation stating that:

> "the specification process for one complex building material took 100 to 150 parameters and 100 phone calls to define, we resolved this by moving the knowledge to the step where the architect specifies that product."

In response to the changing scope and pattern of work introduced by 3D CAD, a designer that successfully implemented the boundary object technological change described that they:

> "bring sub trades forward so that the steel fabricator works with the engineer and the window manufacturer works with the architect… it yields better technical detailing"

In the move from 2D CAD to 3D CAD, work is being redistributed among firms in the network. However these redistributions are not enacted without difficulty. With 3D CAD, some work is redistributed from contractors and suppliers to designers. However, for the network to accrue the benefits of this additional work, the virtual model must be used by firms downstream in the process. One example of a designer's and a fabricator's breakdown in process was described as follows:

> "if everyone doesn't follow the process it all falls apart … if the fabricator ignores the upstream designer's (3D CAD model) in one fell swoop the process is stopped and the benefits disappear"

Examples such as this illustrate the mutual adjustment required by firms in the network in order for implementation of 3D CAD to be a success at the level of the network. If one of the partners fails to adjust and utilize the extra work performed by the designer then 3D CAD implementation fails in the network. Design and construction firms that were able to manage the mutual adjustment process and successfully implement 3D CAD developed tighter collaborations and partnerships. Improving the relationships at the organizational interface in the network enabled design and construction firms the flexibility to redistribute work.

Another key antecedent that relates to the changing patterns of work required by 3D CAD software is the *development of standards for interaction* between firms. After work has been redistributed and firms mutually adjust, design and construction firms must begin accessing and developing a single virtual building information model. One designer described how they addressed the development of interaction standards as follows:

> “we set up coordination between disciplines so that the architect never touches the structural pieces, the structural engineer never touches the architectural pieces and if there is a change, there must be a web meeting … we require on all projects a basic set of rules be followed.”

Alongside the *redistribution of work* and *developing standards for interaction*, both design and construction firms expressed the need to *develop a system understanding* of the design and construction process. In other words, just as shared interests enabled design and construction firms to understand and consider each others' needs, the change in scope and pattern of work required design and construction firms to understand each others' work. Design firms described hiring designers with actual construction experience who understood "how things go together." Construction firms reported similar changes in hiring employees with more design experience.

Change Management

All of the changes discussed thus far relate in some way to how organizations, work patterns, and technologies interact in networks. However, firms also reported addressing issues of change management within their organizations. In design and construction organizations, firms were only able to successfully implement 3D CAD after they were able to *obtain sufficient 3D CAD training*. Another key antecedent for explaining successful 3D CAD implementation was when firms *worked with an external change agent*. Firms described a "Boeing effect" where larger design and construction firms would require the smaller partners in their network to implement 3D CAD. Other firms described certain projects being of such significant importance (e.g., a tall skyscraper or a professional sport stadium) that it drove firms to implement 3D CAD that might otherwise have waited to adopt. In the case of design and construction firms based in Europe, several informants described working with national agencies that cover the initial costs of learning 3D CAD.

Conclusions

This research demonstrates how technological change in boundary objects in interorganizational networks can require considerable mutual adjustment in the interfaces between interdependent organizations. Previous research has shown how changes to boundary objects within organizations have restructured work (Henderson 1991, 1999; Robertson and Allen 1992), changed relationships between employees (Henderson 1999), and changed the skill requirements for the various roles (Manske and Wolf 1989, Salzman 1989) in design firms. Other research on the successful implementation of 3D CAD as an interorganizational information system in the defense aviation industry found agreement on a technology platform and object naming conventions was central to implementation success (Argyres 1999). I observe each of these phenomena occurring in boundary object technological change across organizations in an interorganizational network.

Each of the investigations into the implementation of 2D CAD to replace paper-based drafting discovered that boundary object change restructures work and, in doing so, changes the skill requirements for employees in design firms (Henderson 1991, 1999; Manske and Wolf 1989, Robertson and Allen 1992, Salzman 1989). I identified this in the interdependent work interface that connects designers and contractors. The introduction of 3D CAD across design and construction organizations required work to be restructured, requiring design and construction firms to *redistribute work among firms*. This change also shifted skill requirements across design and construction firms. Firms described needing to *develop a system understanding* of each others' work. This caused both design and construction firms to change their hiring practices and also led to the emergence of new roles within both firms.

In addition to the *redistribution of work* among firms and the *development of a system understanding* of work, in interorganizational boundary object change I identified the need to *develop standards for interaction*. Argyre's (1999) investigation of the implementation of 3D CAD in the defense aviation industry also identified the standardization of work practices as a key component to 3D CAD implementation success. He described a 'deep standardization' which enabled teams from different organizations to work together more seamlessly, decreasing the amount of coordination required to do the work. Within a firm, employees who work together on a continual basis can work together more seamlessly to adjust to changes in work. However, in a network of firms, collaboration on one project does not necessarily mean there will be collaboration on other projects. In the development of the B-2 bomber (Argyres 1999), the firms in the project network will not necessarily work together on the next aircraft development project. In the design and construction industry, projects are generally much smaller in scope and shorter in duration than an aircraft development project. The composition of design and construction firms in a network can be stable, but fluctuations in participation and lapses in time between projects make learning how to work together with the new boundary object a slow process.

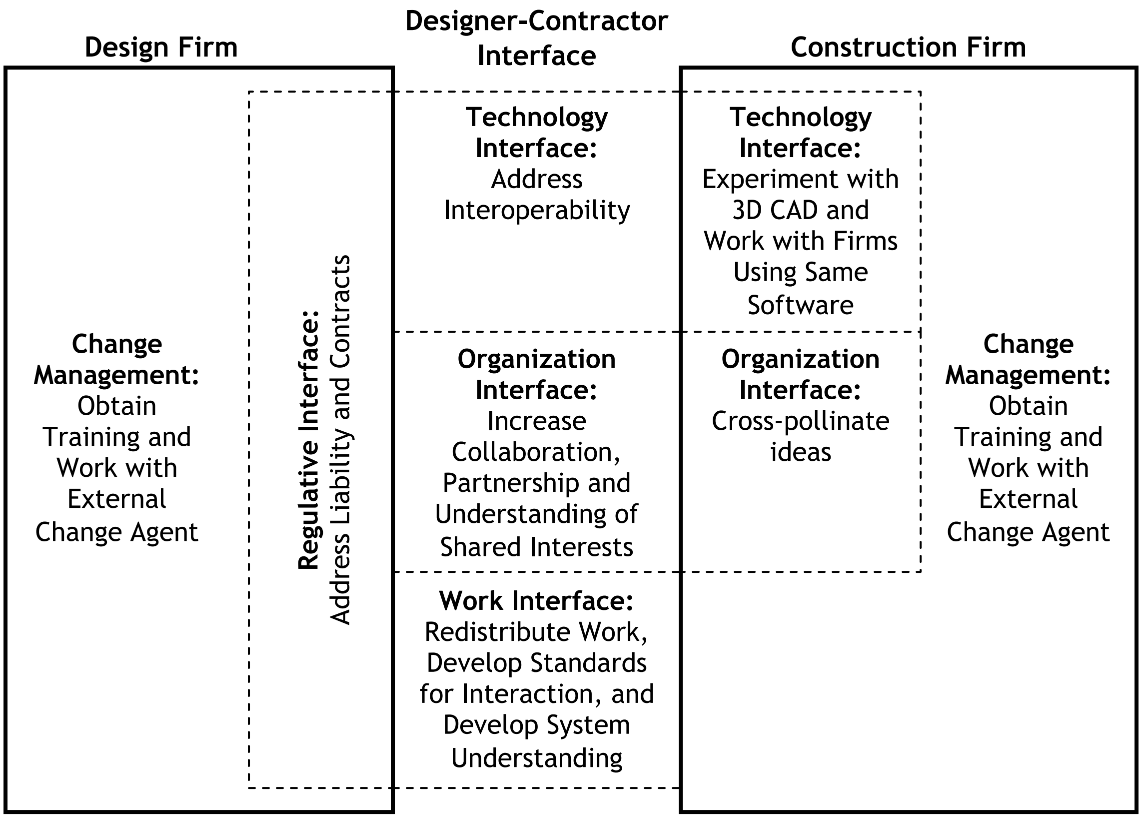
Henderson (1999) described how relationships between employees in design organizations changed as a result of the implementation of 2D CAD. My investigation of interorganizational boundary object change also revealed a significant organizational interface component. Change in the boundary object created changes in the work across design and construction firms. To address the changing scope and patterns of work, firms in interorganizational networks *increased collaboration*, *developed partnerships*, *understood each others' shared interests*, and ultimately were able to *cross-pollinate ideas across firms*. In Henderson's (1999) investigation the evolution from sketches to 2D CAD disrupted relationships and the CAD implementation was described as a failure. I focused my data collection on design and construction firms that had successfully implemented 3D CAD. These firms addressed relational disruptions caused by change in the boundary object by strengthening the relationship between organizations when implementing 3D CAD. Argyres (1999) also identified the importance of a trusting relationship between organizations implementing 3D CAD.

In addition to the organization and work interface concepts identified by previous researchers of boundary object change within firms, I identified regulative interface and technology interface issues in networks. Firms in design and construction networks make technology purchase decisions independently. Where a single organization may standardize on a specific software platform, in interorganizational networks this is not necessarily the case. Argyres (1999) found that the three principal firms in the B-2 bomber development alliance were each using different 3D CAD platforms. They agreed to standardize on a single 3D CAD platform for the B-2 project. Argyres also identified the development of a 'technical grammar' which enhanced the interoperability of the file exchanges. Like the defense aviation network study by Argyres (1999), firms that successfully implemented boundary object technological change in design and construction networks *addressed interoperability of technologies* and *worked with other firms using the same 3D CAD software*. The issue of interoperability has been described as a critical problem in the fragmented design and construction industry. A report by the National Institute of Standards and Technology in the United States described inadequate interoperability of technology in the design and construction industry in the United States alone as a $15.8 billion problem annually (Gallaher et al. 2004). Slow adopting contractors also first *experimented with the technology* before committing to the co-creation of virtual models with design firms. When boundary object change extends beyond the organizations boundaries into a network, issues of technology interfaces must be addressed for successful implementation to be achieved.

In design and construction networks, firms typically enter into collaborative agreements in the form of contracts. However, when boundary object technological change occurs across organizations, the changes in the work interface must be regulated in some way. To a large extent, strengthening organizational interfaces was critical to managing the change in risk profiles associated with the boundary object change. However, certain regulative formalities needed to be introduced at the interface between designers and contractors. Networks that successfully implemented 3D CAD addressed redistribution of work by *addressing liability* and *addressing contractual constraints*. In my study this was particularly important for designers whose scope of work was being increased by the redistribution. Within an organization, issues arising from the redistribution of work would be managed within the hierarchy. However, in interorganizational networks where firms work together in the absence of an orchestrating organization, redistributions of work caused by boundary object technological change can shift liabilities and require new contractual arrangements.

The antecedent constructs at the interface between design and construction organizations relating to the implementation of 3D CAD are illustrated in Figure 3.3. The work interface and the organizational interface antecedent groupings for interorganizational networks replicate and extend the firm-level findings regarding boundary object technological change of Henderson (1991, 1999). The findings are also consistent with work interface issues identified in previous studies of 2D CAD implementation (Manske and Wolf 1989, Robertson and Allen 1992, Salzman 1989). Within a firm, the organization and work interface is between individuals or teams that work together on a more or less continual basis. However, in project-based interorganizational networks, the interface between a pair of specialist organizations on one project may not persist for future projects. The mutual adjustment required to address organization and work interface issues across organizations can therefore be more arduous than across a more stable group of individuals or teams within an organization. The technical interface and regulative interface antecedents were not previously identified in studies of boundary object change within organizations. However, in a study of collaboration and 3D CAD implementation in defense aviation networks, Argyres (1999) identified similar issues at the technological interface between organizations.

Figure 3.3 - Antecedents for Successful Implementation of Boundary Object Technological Change in Design and Construction Networks



Researchers describe boundary objects as flexible devices to connect intersecting social worlds across occupational fields (Bechky 2003, Henderson 1991, 1999; Star and Greismer 1989). In investigations of boundary object change, researchers found that the effect was different for employees from different occupational fields (Henderson 1991, 1999). The findings of my research are consistent with firm-level boundary object change. Designer and contractor implementation perspectives varied significantly across regulative, organizational, and technological interfaces between firms in the network. In Henderson's (1991) investigation of boundary object change to 2D CAD, the status of the design itself was raised. This finding was also consistent in the interorganizational networks I investigated. Informants described 3D CAD models as being integrated into the contract documents, hence becoming a part of the regulative interface.

In addition to the interface antecedent groupings, design and construction firms needed to address internal change management issues associated with the technological change to 3D CAD. Both design and construction firms needed to *obtain training in 3D CAD* before they could successfully implement the technology. Both design and construction firms also described the value of *working with an external change agent* to successfully implement 3D CAD. Though this is not identified in previous studies of boundary object change, interorganizational network researchers have described how external agencies such as the National Institutes of Health in biotechnology networks facilitate change (Powell et al. 2005).

This paper introduces a set of antecedent constructs that interorganizational networks must consider when introducing technological change in the boundary objects that connect their work. Extending knowledge of boundary object change from the organizational to the interorganizational level is critical as the use of interorganizational networks as a form of industrial organization continues to increase. Firms populating these interorganizational networks can increase their competitive advantage through the successful implementation of boundary-spanning technologies. However, firms must understand that boundary object changes impact collective ways of knowing both within and across organizations. This research shows that the impact of known organizational and work interface issues are magnified when extended to interorganizational networks. It also introduces a set of technology and regulative interface concepts that apply to boundary object change in networks. In doing so, this research contributes to a more complete understanding of boundary object technological change. Future research on boundary object technological change in interorganizational networks should focus on elaborating the interface concepts identified in this paper and understanding the degree to which the concepts apply in other contexts.

Chapter 4

Aligning Innovations and Networks: Toward a Theory of Innovation in Interorganizational Networks

Abstract

I contend that current theories of innovation are inadequate to encompass innovation in interorganizational networks. To date, innovation research has predominantly focused on hierarchically-organized bureaucratic organizations competing within the context of single markets. Meanwhile, researchers report a proliferation of the interorganizational network form of organization replacing traditional vertically integrated hierarchies over the past two decades. Interorganizational network researchers who address the subject of innovation arrive at contradictory findings. One camp of researchers finds networks to be a locus for innovation, while another finds that networks stifle innovation. I argue that these contradictory findings result from the failure of previous research to link firm- and network-level implementation processes explicitly to market-level innovation outcomes. In this paper, I resolve this contradiction by introducing a new theory for innovation in interorganizational networks. I analyze the adoption of three comparable technological innovations in computer-aided drafting through networks comprised of 82 firms in the United States

and Europe. I observe that the allocation of work and the role relationships between specialists in the network vary across markets. I find that (1) innovations that align to the allocation of work in the network diffuse more quickly and (2) role relationships between firms in the network mediate the impact of misalignment on diffusion. I apply these findings to induce a two-stage theoretical model for innovation in interorganizational networks. The model helps to resolve the paradoxical innovation findings of earlier network researchers.

Introduction

Researchers investigate implementation processes and diffusion outcomes for innovations to both understand and improve their market acceptance rates. Until the 1980s, researchers explored innovations primarily from the standpoint of their impact on industrial systems (Schumpeter 1942), their diffusion through populations of adopters (Rogers 1962), the economic impacts of an innovation from the perspective of the firm (Mansfield 1968), the economic impacts from the perspective of the exchange (Katz and Shapiro 1986), or to understand attributes of the innovation itself, such as the concept of dominant designs (Abernathy and Utterback 1978). It was not until the 1980s that researchers started to provide some dimension to the broad concept of innovation when they explored the varying impact a specific innovation would have on adopters or on populations of adopters. Innovations could then be categorized along a continuum from incremental (implying only a modest change) to radical (implying significant change). Researchers sought to test these concepts empirically (Dewar and Dutton 1986), to ascertain their relative impact on firm competences (Tushman and Anderson 1986), to use them to enrich economic theory

(Nelson and Winter 1982), and to investigate the impact of different firm strategies and structures on innovation rates (Ettlie et al. 1984).

In 1990, Henderson and Clark (1990) posited that innovations need to be framed with respect to the impact the innovation will have on linkages between core concepts and components. This added another important dimension to innovation research. They illustrated through case evidence from innovations in photolithographic equipment how minor changes in core concepts (what was heretofore described as incremental innovation) could have significant consequences on innovation outcomes when the linkages between core concepts and components were disrupted. Over the last several decades, innovation researchers have developed and tested a rich framework for innovations. A number of researchers contend that technological change is only one side of a two-sided coin. To understand technological change we must consider it as being in a dynamic state of mutual adaptation with the organization (Barley 1990, Leonard-Barton 1988, Orlikowski 1992). A fully developed framework for innovation would thus include constructs relating to organizational adaptation and constructs relating to the technological innovation.

Organizational innovation research to date has predominantly focused on hierarchically-organized bureaucratic organizations competing within the context of single markets. Afuah (2001) is a notable exception, observing how an innovation in reduced instruction set computing (RISC) impacts efficient buyer-supplier organizational boundaries. He concludes that innovation studies are incomplete if they do not look beyond focal firms. A growing body of organizational research explores a relatively new form of organization, the interorganizational network. More than a decade has passed since researchers of interorganizational networks exposed the proliferation of this form of organization vis-à-vis hierarchy (Barley et al. 1992, Kanter 1991, Pekar and Allio 1994). Pekar and Allio (1994, p. 54-55) found that whereas Fortune 500 companies formed 7,100 alliances in the period from 1950 to 1987, a noteworthy 20,000 alliances were formed in the ensuing period from 1988 to 1992 alone. Given this rapid growth in the formation of interorganizational networks, coupled with a parallel exponential growth in the number of journal articles on the subject in recent years (Borgatti and Foster 2003), it is surprising that innovation researchers have largely ignored this organizational development.

With a burgeoning literature on interorganizational networks, one might expect network researchers themselves to explore the subject of innovation. For a quarter of a century, network researchers have studied the economic (Eccles 1981, Williamson 1975, 1985) and sociological (Granovetter 1985, Powell 1990, Uzzi 1997) foundations of the network form of organization. Though there is general agreement among researchers that organizing into networks leads to improved performance (Gulati 1995, Hamel 1991, Powell et al. 1996), only a handful of studies discuss the implications of the networked organizational form for innovation; and none of those that do explicitly link network processes to innovation outcomes.

This bias in the network literature led Podolny and Page (1998, p. 73) to suggest that the interorganizational network literature "runs the risk of succumbing to a naïve functionalism." However, upon a closer examination of this literature, I identify a growing discord among network researchers on the subject of innovation. One cluster of researchers focuses on the ability of a network of firms to produce novelty. Powell and his colleagues (1996) concluded that the interorganizational network itself could be viewed as the locus for innovation and learning, in their investigation of biotechnology networks. In contrast, a second cluster of researchers identifies concomitant issues for innovation associated with learning in networks. Lampel and

Shamsie (2003, p. 2206) caution strongly against the use of interorganizational networks, finding an "evolutionary stagnation in the craft of making movies" associated with the adoption of the network form of organization in the Hollywood motion picture industry.

The two contrasting perspectives on innovation in interorganizational networks emerged from studies that were motivated to advance our understanding of networks, not innovation. Not only do we lack a theory for innovation in interorganizational networks, but the paucity of research that discusses innovation in the context of network studies arrives at contradictory results. To develop a theory for innovation in interorganizational networks and to resolve the identified paradoxical perspectives, researchers need to link implementation processes in firms and networks explicitly to innovation outcomes at the market level. This paper provides such an integrated perspective of implementation processes and diffusion outcomes for innovation in interorganizational networks.

Given the widespread adoption of the network form of organization, it is critical that paradoxical interpretations of networks as 'loci for innovation' or paths to 'evolutionary stagnation' be resolved. In this paper I investigate the implementation processes at the firm and network level for three comparable software innovations. I then link the observed implementation processes to market level diffusion outcomes in the United States and Europe. In integrating perspectives across multiple levels of analysis I develop a grounded theoretical model for understanding innovation in the context of interorganizational networks.

Research Setting and Methodology

In this paper I explore the impact of the network form of organization on implementation processes and diffusion outcomes for innovations. I designed the research to collect data at three distinct levels of analysis. In order to capture the implementation processes in the networks I investigated firm and inter-firm implementation processes. In doing so I collected data at the both the firm and the network level. I collected data at the market level on innovation diffusion outcomes. I collected this data from the companies that produce the three software innovations I investigated.

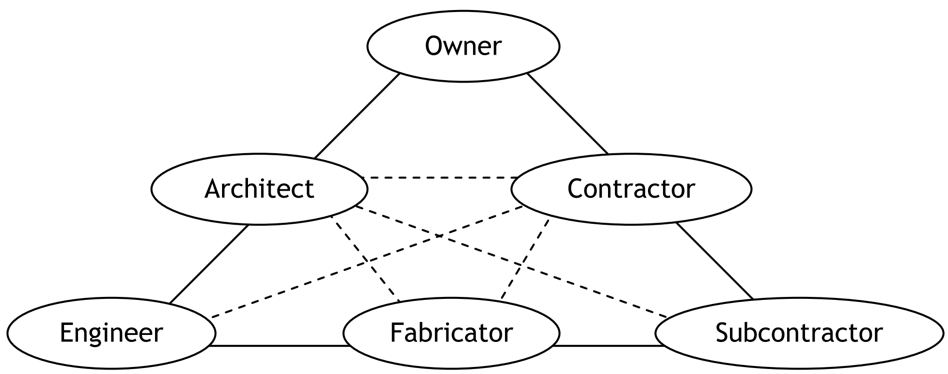
Construction Industry Network Focus

Early research on interorganizational networks focused on the construction industry. Eccles (1981) introduced the notion of the interorganizational network into the literature when he identified *quasi-firms* in the Massachusetts building industry. *Quasi-firms* were described as having stable and continuous relationships over long time periods. Dioguardi (1983) supported this view and described the ways that construction networks co-evolve with information technologies and management practices. Interorganizational network researchers typically point to construction as exemplifying the network form of organization (Powell 1987, 1990).

The construction industry is a mature industry that has organized into networks since the 1950s (Stinchcombe 1959). Many of the industries being investigated in interorganizational network research are relatively new, having adopted the network form of organization since the 1990s (Lampel and Shamsie 2003). Because my goal was to observe changes in processes associated with the implementation of a new technology, the maturity and stability of the construction industry networks enabled me to transparently observe variations in process resulting from the implementation of the innovation.

In most cases, the construction networks I researched consisted of an owner, an architect, an engineer, a general contractor, numerous subcontractors (e.g., plumbing, HVAC, electrical, framing), and fabricators (see Figure 4.1). I define the network as the group of specialist firms contracted to work together on specific construction projects. I 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 design and fabrication of a structural system for a building, or the design and construction of a home.

Figure 4.1 - Network of Construction Specialist Firms



________ Contractual linkage (including communication and interdependence linkages)

- - - - - - - - - Communication and interdependence linkages

I introduced variation into the research design by focusing on networks in two distinct markets. Glaser and Strauss (1967) suggest that maximizing variances in research designs enables researchers to develop dense categories and identify fundamental uniformities. Because we lack a foundation of research and constructs at the intersection between innovation and interorganizational network research, I designed a cross-national investigation to capitalize on national variances in identifying the relevant constructs and dimensions. 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).

The "varieties of capitalism" approach is a relevant dimension upon which to introduce variance. The definition of liberal *vs.* coordinated market economies implies some variation in inter-firm relationships across countries. Consequently, I chose to concentrate my data collection efforts on construction industry networks in the United States and Finland (though some important, anecdotal evidence is also included in studies from France and Germany) on the basis that they provided "polar" contrasting cases (Pettigrew 1990). Networks selected for inclusion in the study were selected on the basis of their ability to support analytic generalization (Yin 1989), in other words, I selected specific networks that were in the process of implementing one of the three building information modeling applications investigated in the study.

Building Information Modeling Innovations Studied

I identified three comparable technological innovations in the construction industry on which to focus my 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 work together to build shared, three-dimensional computational models of buildings with intelligent objects. This new functionality is described in the industry as "virtual design and construction", "model-based design", and "building information modeling". I will refer to this new generation of CAD software as building information modeling software, or BIM for brevity. 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 and related data. Only recently, however, have mainstream CAD software vendors begun marketing object-oriented building information modeling systems that seamlessly integrate 3D geometry at the building component level with a wide variety of data.

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 their interdependencies with other specialists in the network. Firms continued to exchange sets of final 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 information continued to be affected, for the most part, through exchange of 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.

In contrast to these two prior innovations, 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. Therefore, I chose to focus on the move to building information modeling as a network-level innovation in the construction industry network. Each of the building information modeling vendors included in the study had sales in both the United States and Europe.

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

The first innovation I studied, which I will refer to as Building Modeler, was developed by a global software firm based in the United States that has 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 my study, which I will call Structural Modeler, is produced by a global software development firm based in Finland that focuses its product development and marketing on structural engineers. This firm also has offices in the United States. I refer to the third application included in my study as the Home Modeler. The company that created Home Modeler operates in the United States through a subsidiary but is based in Finland. Its building information modeling application targets the homebuilding market.

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 I investigate three technological innovations diffusing through construction networks in the United States and Europe. I employ multiple data collection methods; including, ethnographic interviews, direct observation, and review of primary and secondary documentation. By triangulating the findings across these different data collection methods I strengthen the validity of my 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. I 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 my data was collected from the United States and Finnish construction networks included in the study. I 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 I 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 I spoke to more senior managers. In all cases I focused the interview discussion on specific project experiences where transitions to building information modeling applications occurred.

In addition to interview discussions, direct observations were made within and across specialist firms to observe the changes in process associated with implementing building information modeling applications. I was invited to attend company meetings and project discussions, to visit project sites both under construction and recently completed, and to generally observe the interactions between specialists in the network relating to the implementation of BIM. I took extensive notes during this process and took digital photographs for use in the 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, I requested hard copies of materials discussed during interviews 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 interorganizational practices of the network in adopting building information modeling applications. This primary documentation was attached to my field notebooks and often elucidated concepts that were not entirely clear when reviewing the notes from an interview or observation. I also obtained temporary licenses for the building information modeling software from one of the three vendors included in the study. This allowed me to develop a familiarization with the technologies being adopted by the United States and Finnish construction networks that I 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. I was able to attend a conference related to building information modeling applications 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, I was able to review my findings and thereby further increase the validity of the constructs. Overall, I was able to manage the reliability of my findings by keeping an indexed, organized database of my 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 innovations in interorganizational networks. Finally, a set of propositions was developed to provide the foundation for a grounded theoretical model for innovation in networks.

Aligning Innovations and Networks

I 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 innovations are implemented in and diffuse through networks of firms. Some innovation research (Afuah 2001) finds that organizational boundaries make adapting to an innovation and developing appropriate transition strategies difficult. Afuah (2001) concludes that innovation studies that only include focal firms are incomplete. In this research I found that the key to understanding innovation in networks lay in a finer-grained understanding of how work is allocated across boundaries in networks and of role relations between specialists in the network.

Allocation of Work to Specialists in Networks

During my data collection effort in Finland, I was 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 I sought to understand how the firms in one Finnish network used the Home Modeler building information modeling application. I was 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, I was 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 practice, 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:

> "in design professional's drawings, the dimensions are not exact, a contractor interprets these and creates shop drawings with exact dimensions … if a dimension is wrong it's the contractor's fault, if derived from the 3D CAD model the architect would be responsible."

To confirm the generality of this work allocation practice, I 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, I was 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.

My 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, I 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. I will discuss the implications of this finding in a later section.

Network and Innovation Alignment

Building Modeler

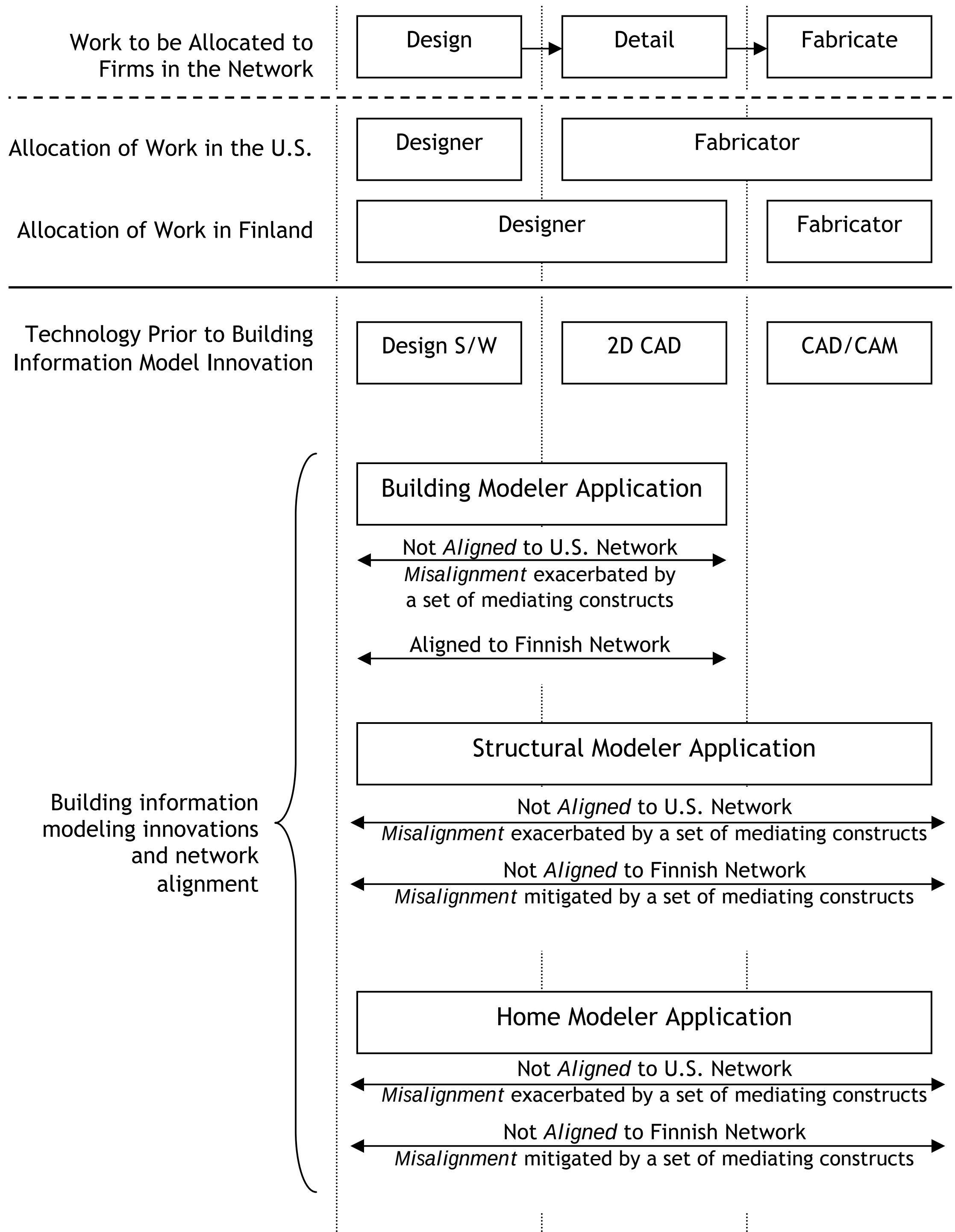
The Building Modeler application replaced existing technologies for conceptual architectural design and detailing into an integrated building information modeling package. In Finland where construction networks allocated design and detailing work to designers, this integrated technology was able to diffuse 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 a specialist other than the architect in the network. 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 it.

Comparing market acceptance for the Building Modeler application in the United States and Finland I 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 (see Figure 4.2). The application provided more functionality than was required by the architects and insufficient functionality for downstream network partners. Though the Building Modeler vendor would not disclose exact diffusion figures, they provided a telling anecdote about the diffusion of their product in the *aligned* Finnish market versus the *misaligned* U.S. market. The firm had projected a certain diffusion rate in each of these two markets, based on their experience with previous innovations. To their great surprise and delight, the Building Modeler innovation far exceeded predictions of diffusion in the Finnish market. Conversely, in the U.S. market the Building Modeler innovation failed to come close to predicted diffusion rates.

Figure 4.2 – The Alignment of Innovations and Networks in the United States and Finland



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 4.2) 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 exploring the variable impact of *misalignment*.

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.

Home Modeler

The Home Modeler building information modeling application integrated the technologies involved in design, detailing and fabrication for home construction. Limited market adoption 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.

The Impact of Alignment on Diffusion

The consistent findings across the three building information modeling innovation cases lead to the formulation of the following general proposition. I will treat the case of misalignment in more detail in the following section.

> **PROPOSITION 1.** *If an innovation aligns to the allocation of work in an interorganizational network, it will diffuse more rapidly than if it is misaligned to the allocation of work.*

Misalignment and Network Dynamics

Building Modeler provided a unique case in which the innovation aligned to the allocation of work in Finnish construction industry networks. However, the Building Modeler in the United States and the Structural and Home Modeler in both the United States and Finland were misaligned to the allocation of work. The impact of the misalignment on implementation processes and innovation outcomes varied significantly between the United States and the Finnish networks. In the following sections I describe a set of constructs relating to implementation in networks that mediated innovation outcomes.

Relational Stability

In Eccles' (1981) 25-year old 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 choosing partners offering the lowest price. Interestingly, in my study, I found that Finnish construction networks currently contract very much along the lines described by Eccles, with firms engaging in tight partnership relationships with one to three firms for each specialist type in the network. In contrast, construction networks in the United States currently tend to adopt shorter-term relationships than those identified in Eccles' study. Interviewees in United States construction firm networks disclosed that they contract with five to six different firms for each specialist firm type. 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 a larger set of partner firms in the United States.

I describe the degree of stability in network role relations as *relational stability*. Networks in the Finnish construction industry exhibited strong *relational stability* by choosing to work with only one to three firms for each specialist type. As predicted by the Hall and Soskice (2001) work on varieties of capitalism, members of networks in this coordinated economy tended to choose partners based on previous working relations. In contrast, construction networks in the United States exhibited weak *relational stability* due to the fact that members tended to choose from among five or six firms for each specialist type. Firms in the United States networks were more concerned with getting a low price than working with the same set of firms from project to project.

The *relational stability* construct relates to several other constructs explored in organizational research. For example, Stinchcombe (1968) described the process of having to socialize new members in a group as the rate of social reconstruction. Interorganizational network researchers describe the phenomenon where firms are socialized into networks as embeddedness (Granovetter 1985, Uzzi 1997). Though embeddedness is a multifaceted term, Granovetter describes it in terms of on-going patterns of relations in economic exchange. This is consistent with the Eccles (1981) conceptualization of the *quasi-firm* in construction.

Each of the three innovations achieved unexpectedly slow rates of diffusion in the United States. In each of these cases the innovation was misaligned with the *allocation of work* in the U.S. networks. Weak *relational stability* in those networks created difficulties for firms implementing these innovations because learning from one project failed to carry forward to the next project when membership in the project networks shifted significantly from project to project. Learning occurred more slowly within firms because the weak *relational stability* limited the number of times they would be exposed to the innovation. However, much more insidious is the fact that inter-firm learning — the development of interorganizational routines — failed to accumulate as a result of the limited opportunities for specific specialist firm pairs to work together. Since each of these innovations required firm networks to shift the allocation of work and to resolve new kinds of interdependencies, the weak *relational stability* exacerbated problems associated with implementing the application in the network and led to much slower diffusion than expected.

In contrast, the strong *relational stability* in the Finnish networks mitigated the impact of misalignment on diffusion for the Structural Modeler and Home Modeler innovations. Both of these innovations diffused rapidly through the Finnish market —

and through the French and German markets — in the case of the Structural Modeler innovation. Because the Building Modeler innovation actually aligned to the allocation of work in the network, the *relational stability* between firms was not an issue and the diffusion for that particular innovation far exceeded the expectations of the firm that created the application.

> **PROPOSITION 2a.** *The weaker the relational stability in an interorganizational network, the greater the difficulty to achieve network-level learning. This contributes to slower innovation diffusion rates.*
>
> **PROPOSITION 2b.** *The stronger the relational stability in an interorganizational network, the lesser the difficulty to achieve network level learning. This contributes to faster innovation diffusion rates.*

Interests

A second contrasting construct between the Finnish and United States network implementation processes related to firm-level versus network-level *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 its customers or network partners that it was using the Building Modeler application even though its managers acknowledged that sharing such information and files would greatly reduce downstream workload and reduce errors. They stated clearly that they wanted the benefits of the new technology to accrue only within their own firm. Firms in U.S. networks also expressed concerns over other firms exhibiting strategic, self-interested behavior. In other words, they were concerned that their trading partners would use the change required by shifting allocations of work to game them on price.

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 its own electronic CAD files for manufacturing. In the case of the Home Modeler innovation, one Finnish contractor described how it brought all of its impacted network partners to sit around a table and discuss how the change would impact each firm, so that the costs and benefits of the innovation could be equitably distributed across the network.

Williamson (1985) discusses *interests* in his work on transaction cost economics and economic exchange. He describes hybrid forms of organization (essentially interorganizational networks) as relying on "mutual interests" (Williamson 1985, p. 155) to minimize transaction costs by limiting the impact of opportunism and mistakes. The concept of *interests* also relates to the embeddedness construct described by Granovetter (1992) and related to the *relational stability* construct. Granovetter argues that the deeper the embededdness, the more likely firms in a network are to see their *interests* as aligned rather than opposed. This is consistent with what I observed in the U.S. and Finnish networks.

When *interests* accumulated at the level of the firm, as was the case for the U.S. networks studied, the effect was to exacerbate the impact of *misalignment* on diffusion. By considering only their own *interests* and not attempting to share the benefits of the innovation with their trading partners, firms in U.S. networks were restricting the rate of diffusion of the innovation. In contrast, in the Finnish networks the *interests* were defined at the network level, alleviating fears of opportunism and increasing firms' willingness to share the benefits of innovation with their partners. In these networks, the network level accrual of *interests* mitigated the impact of misalignment on diffusion.

> **PROPOSITION 3a.** *If interests are centered on the firm in an interorganizational network, the network will adopt misaligned innovations more slowly. This contributes to slower innovation diffusion rates.*
>
> **PROPOSITION 3b.** *If interests extend to the network in an interorganizational network, the network will adopt misaligned innovations more quickly. This contributes to faster innovation diffusion rates.*

Boundary Strength

Another construct that helped to explain the contrasts between U.S. and Finnish interorganizational networks was *boundary strength*. The strength of organizational boundaries played a critical role in how networks adapted to *misaligned* innovations. In the United States the *boundary strength* between firms in a network was comparatively rigid. In the adoption of the Building Modeler innovation in the United States, several firms vertically integrated into a single firm when attempts at redistributing work in the network failed. Each of the building information modeling innovations required the designer to increase his or her knowledge of the objects they were designing. An example observed many times in the data collection was the situation where the wall of a room meets the ceiling. In 2D CAD it sufficed for the architect to just draw a line where the wall meets the ceiling. However, with building information modeling, the designer has to define the way in which the wall object is connected to the ceiling object. This requires greater knowledge of how the structure will be constructed in the field. In U.S. networks architects generally refused to take on this additional responsibility since it did not fit with a standard interpretation of their role in the network. In contrast, Finnish firms adopting the Home Modeler application redrew the organizational boundaries separating the firms in the network without losing their firm identity. The architect took on aspects of the work that had previously been completed by the builder so that the network of firms was quickly able to garner the benefits of the misaligned innovation.

Researchers are beginning to explore the role of organizational boundaries in interorganizational networks. Jacobides and Winter (2005) investigate integration and disintegration in Swiss watch making as a function of organizational capabilities. Likewise, Afuah (2001) explores the role of vertical integration in the face of technological change in the RISC industry. Both of these studies explore organizational boundaries from the perspective of where they should be circumscribed. Should firms integrate to eliminate boundaries in the face of technological change, as was the case on one of the U.S. networks I investigated? Or, should firms in the network remain independent?

In the case of the networks I investigated, the *boundary strength* in the U.S. networks was rigid. Because they continued to work with so many different network partners across projects, firms in the United States found it more difficult to negotiate changes in their organizational boundaries with other firms in the network to accommodate the misaligned innovation. This contributed to a reduction in the rate of diffusion. Interestingly, in the case of one network, the rigid boundaries separating firms in the network were removed when the contractor in the network decided to vertically integrate a set of specialist firms from the network into its own organization. This led to tremendous productivity improvements as it reduced the impact of the weak *relational stability* and the firm level *interests*. However, it did not positively influence the diffusion outcome because not many others in the industry followed the same strategy of integration. In the case of the Finnish networks, the *boundary strength* was fluid. Firms in the coordinated market economy in which Finnish networks form and operate were able to reallocate work across fluid boundaries as necessary to accommodate a *misaligned* innovation. This capability mitigated the impact of the *misalignment* of an innovation on its rate of diffusion.

> **PROPOSITION 4a.** *If the boundary strength between firms in a network is rigid, networks will have significant difficulty adapting to misaligned innovations. This contributes to slower innovation diffusion rates.*
>
> **PROPOSITION 4b.** *If the boundary strength between firms in a network is fluid, networks will have little difficulty adapting to misaligned innovations. This contributes to faster innovation diffusion rates.*

Agent for Network-level Change

A final construct identified in comparing Finnish and United States construction networks was the presence of an *agent for network-level change*. In the liberal market economy context of the United States, firm networks must be self-organizing in the face of pressures for network-level change. The knowledge of an innovation among firms in the network can be distributed unevenly across multiple firms in networks. Moreover, discussions among groups of firms to assess needed changes can easily contravene tough U.S. anti-trust laws and be viewed internally or externally as illegal collusion. Thus, rational self-organization among firms in the United States firm networks 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 Finland, TEKES, the national technology funding agency, promotes network-level productivity enhancing changes by organizing firms into partnership networks to adopt innovations it regards as promising, and by directly subsidizing the costs such a change may have on individual firms in the network. It subsidizes these costs by funding the applied research on issues associated with early adoption of the innovations. In doing so, the national technology funding agency fulfills the role of an agent for network-level change.

> **PROPOSITION 5a.** *In the absence of an agent for network-level change, networks will have difficulty self-organizing to adopt misaligned innovations. This contributes to slower innovation diffusion rates.*
>
> **PROPOSITION 5b.** *In the presence of an agent for network-level change, networks will benefit from orchestrated change. This contributes to faster innovation diffusion rates.*

Two Stage Model for Innovation in Interorganizational Networks

I summarize the constructs identified in comparing United States and Finnish construction networks and their related dimensions in Table 4.1. The table includes both the *alignment* construct and the four constructs relating to network dynamics in situations of innovation *misalignment* (*relational stability*, *interests*, *boundary strength*, and *agent for network-level change*). Taken together, this set of constructs and related propositions provide the foundation for a new theoretical framework for understanding innovations being implemented by and diffusing through networks of firms.

Table 4.1 - Comparing Construction Networks in Finland and the United States

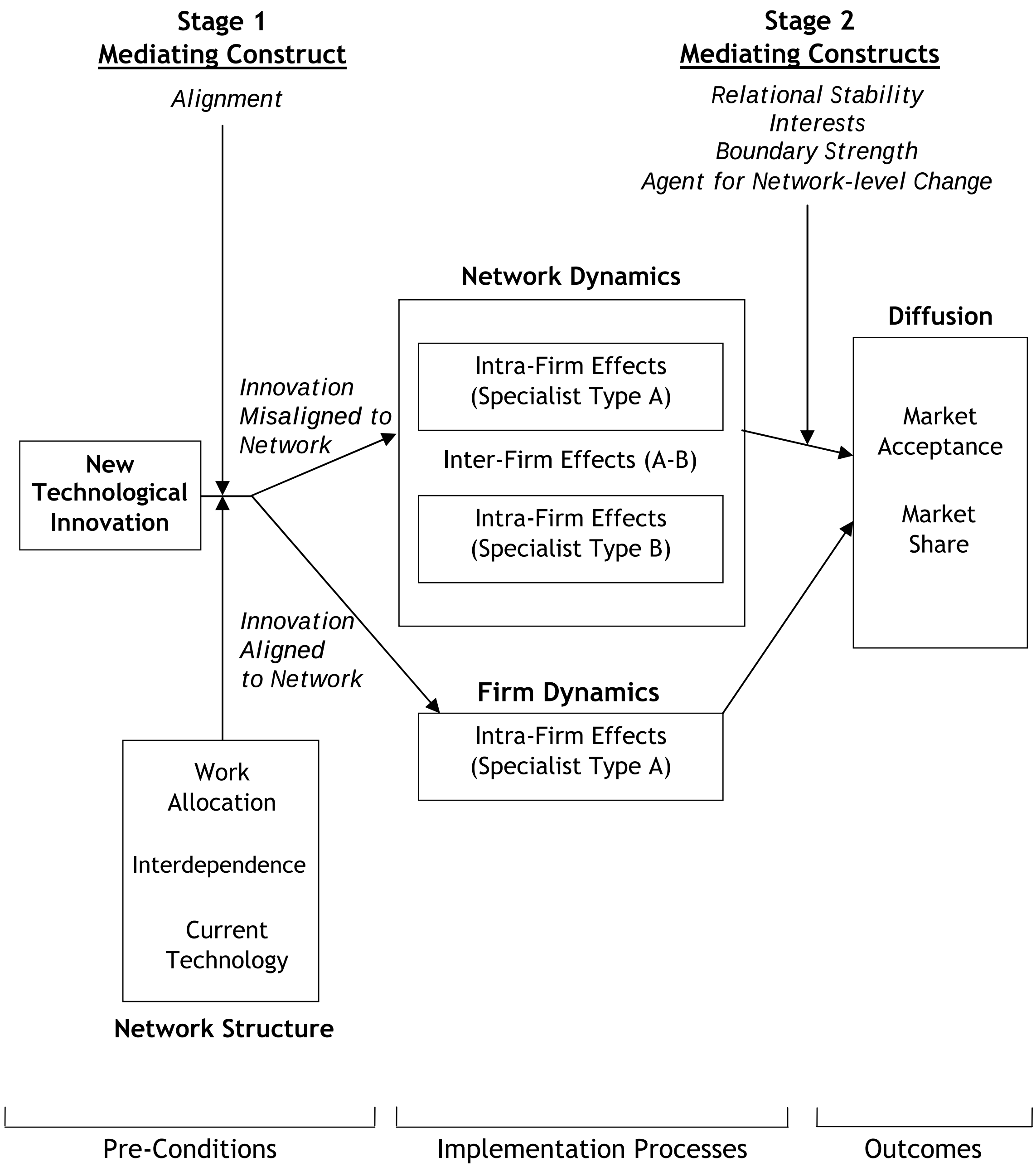
	Country in which Construction Network Exists	
Construct	United States	Finland
Alignment	Derives from *Allocation of Work* in the United States	Derives from *Allocation of Work* in Finland
Relational Stability	Weak (Tendency to contract from 5-6 firms per specialist type)	Strong (Tendency to contract from 1-3 firms per specialist type)
Interests	Firm	Network
Boundary Strength	Rigid	Fluid
Agent for network-level change	None (Network is self-organizing)	National Technology Funding Agencies

Network Structure

Before we can understand the impact and outcomes of technological innovation on a network or a population of networks, we must understand the pre-existing network structure. One key aspect of the network structure identified in this paper is the *allocation of work* to specialists in the network. Because firms in the network must work together to complete some overarching task (e.g., the design and construction of a building, the production and distribution of a motion picture, or the testing and development of a new drug) certain task interdependencies exist that structure the flow of work between firms in the network (Thompson 1967). Sharma and Yetton (2003) demonstrated the importance of understanding these task interdependencies in relation to the successful implementation of information systems. The current technology used by firms in the network is also an important element of the network structure.

In this paper, I illustrate how the *allocation of work* can vary across markets. However, one would expect *allocations of work* to vary within some markets, in particular as innovations spread from one industry segment to another. When an innovation is introduced into the network, the *alignment* of that innovation to the *allocation of work* in the current network structure must be ascertained before the network dynamics can be predicted. *Alignment* then becomes the mediating construct of the first stage of a model for innovation in interorganizational networks (see Figure 4.3 below). Innovations that *align* to the *allocation of work* will avoid the difficulties associated with implementing innovations in interorganizational networks. These innovations can be understood applying current innovation theoretical frameworks of organizational innovation (Rogers 1962). However, innovations *misaligned* to the *allocation of work* in the network will undergo an implementation process unique to interorganizational networks. These innovations do not fall within the confines of existing innovation theory.

Figure 4.3 - Two Stage Model for Innovation in Interorganizational Networks



Network Dynamics and Diffusion Outcomes

Innovations that are *misaligned* with the *allocation of work* in the network will require multiple, interdependent types of specialist firms to mutually adapt to changes introduced by the innovation. Therefore, there is a set of firm effects that can be understood using existing innovation theory as in the case of *aligned* innovations. However, in the case of *misaligned* innovations more than one type of specialist firm population must adapt to the change. This impacts the rate at which the network can adapt to the change. Network dynamics caused by the inter-firm effects, however, have a far greater impact on the diffusion outcomes. The inter-firm effects invoke a second set of mediating constructs (see Figure 4.3). The degree to which diffusion outcomes are impacted by innovation *misalignment* is determined in this second stage of my grounded model for innovation in networks. The values for the four mediating construct dimensions determine the degree to which *misalignment* effects are mitigated or exacerbated. Strong *relational stability*, network-level *interests*, fluid *boundary strength*, and the existence of an *agent for network-level change* will mitigate the impact of *misalignment* on diffusion. Conversely, weak *relational stability*, firm-level *interests*, rigid *boundary strength*, and the absence of an *agent for network-level change* will exacerbate the impact of misalignment on diffusion.

Conclusions and Implications

The findings from the three innovations in building information modeling demonstrate that an *alignment* of innovations to interorganizational networks greatly increases the rate of market acceptance for innovations. Data from construction networks in Finland, Germany, France, and the United States show that in cases of *misalignment* of innovations to the *allocation of work* in networks, stronger *relational stability* in the network can mitigate the impact of *misalignment* on diffusion. In addition, I find evidence that fluid *boundaries* between firms, network-level accrual of firm *interests* and the presence of an *agent for network-level change* can all mitigate the effects of *misaligned* innovations in interorganizational networks. These constructs and a set of related propositions are used to build a grounded two-stage model for innovation in interorganizational networks. This research, therefore, contributes to a fuller understanding of innovation by extending previous organizational innovation theories to include innovation in interorganizational networks.

Because my model incorporates how one network can be more successful with innovation than another, it addresses the current tension in the interorganizational network literature about the impact of networks on innovation. Networks adopting an innovation that *aligns* to the *allocation of work* – or that exhibit strong *relational stability*, network-level *interests*, fluid *boundaries*, and the existence of an *agent for network level change* when faced with a *misaligned* innovation – will perform comparatively better than other networks. In the studies by Powell and his colleagues (1996, 1998), which viewed networks as a locus for innovation, they described biotechnology networks as developing tight, knowledge sharing partnerships (strong *relational stability*) and discussed the important role of the National Institutes of Health (*agent for network-level change*). Also because the interdependencies were more resource than task based, *allocations of work* would play a diminished role in determining innovation outcomes. My two-stage model for innovation in interorganizational networks would predict that these biotechnology networks would be successful innovators.

In contrast, the motion picture industry networks investigated by Lampel and Shamsie (2003) exhibited no clear *agent for network-level change*. The authors describe the move to networks as disturbing the value orientation of individuals and firms toward changes to the network as a whole. This suggests both a lack of an *agent for network-level change* and a firm-level accrual of *interests*. The model would predict that these motion picture industry networks would have some difficulty with innovation. Therefore, the model can simultaneously accommodate the ‘locus of innovation’ findings of Powell and his colleagues (1996, 1998) and the network ‘stagnation’ findings of Lampel and Shamsie (2003). This model then provides a first step toward resolving divergent views on innovation in interorganizational networks.

Chapter 5

Contributions

The three perspectives in this dissertation contribute to a more complete understanding of innovation in interorganizational networks. Each perspective builds upon the previous perspective. However, each perspective also makes a distinct contribution to the academic literature. I will discuss the theoretical contributions for each of the three perspectives in this dissertation in the following three sections.

Perspective 1: Systemic Innovation

Chapter 2 of this dissertation presents the exploratory analyses that led to the more substantial data collection efforts for the papers in Chapters 3 and 4. Although the first perspective on systemic innovation was an exploratory investigation, there were several theoretical contributions in the paper. In the paper we ask several interrelated questions. We were motivated to pursue the paper in order to understand *what explains the difference in innovation perspectives in the building industry innovation literature*? Previous researchers had found the building industry to be relatively innovative (Arditi and Tangkar 1997) while at the same time others found the industry to have difficulty with innovation (DuBois and Gadde 2002, Gann and Salter 2000, Winch 1998). Our conjecture was that the disparity between viewpoints on the innovation capability of the building industry lay in a more nuanced investigation of the type of innovation.

Taking data from a United States Congress Office of Technology Assessment special report (1986), we identified how two innovations in the building industry diffused at markedly different rates. A pre-fabricated subcomponent wall innovation diffused four times more slowly than a related prefabricated lumber truss innovation over the same period. We argue that the scope of an innovation—whether it is incremental or systemic—influences the rate of diffusion in project-based industries. Considering the type of innovation being adopted contributes to an explanation for why the building industry can at the same time be described by researchers as being innovative and non-innovative. We demonstrate that systemic innovations diffuse more slowly than comparable incremental innovations in the building industry.

We proposed that the difficulty with the adoption of systemic innovations in the building industry may reside in the project-based nature of the work. We then asked the question *what explains the different innovation rates in the building industry*? We reviewed the existing literature on the structural characteristics of the building industry that may impact innovation. These studies fell into three broad areas; the impact of regulation on diffusion (Gann et al. 1998, Oster and Quigley 1977), the impact of decentralization (DuBois and Gadde 2002, Gann and Salter 2000, Winch 1998), and examinations of diffusion (Arditi and Tangkar 1997, Blackley and Shepard 1996, Lutzenhiser and Biggart 2003). None of these studies considers the scope of an innovation or focuses on systemic innovations to understand the impact of project-based-organization on diffusion. In fact, the Lutzenhiser and Biggart (2003) work claims that only incremental change is possible in the building industry. We depart from these earlier innovation studies by focusing our investigation on systemic innovations.

Because our research contributed a first investigation of systemic innovation in the building industry we narrowed our research question to understand *what are the fine-grained mechanisms inherent in the project-based building industry that contribute to slower rates of diffusion for systemic innovations*? To accomplish this we conducted two exploratory case studies of the implementation of two different systemic innovations. The first case was an innovation in supply chain practices that required mechanical, electrical and plumbing contractors to change their practices. The second case was an innovation in wall building systems that required the home builder and its framing, mechanical, electrical and plumbing subcontractors to change their practices. Our investigation revealed four constructs that impact the diffusion of systemic innovations across these two industry networks; *organizational variety*, *degree of interdependence*, *boundary strength*, and *span*. Based on these provisional constructs, we suggest that the mixed-influence diffusion model (Bass 1969) be revised to account for the mutual adjustments required when systemic innovations are introduced in project-based industry networks. This exploratory research extends previous research on market level innovation processes focused on incremental innovations and contributes a set of structural mechanisms that impact systemic innovation diffusion rates and a proof-of-concept model for understanding how mutual adjustments associated with those constructs may impact diffusion outcomes. Furthermore, it rebuts previous claims that only incremental innovation is possible in the building industry (Lutzenhiser and Biggart 2003). Systemic innovation is possible; however, the project-based nature of the industry networks makes implementing innovations of this scope more difficult.

Perspective 2: Boundary Object Change

The first perspective in this dissertation on systemic innovation was based on an exploratory data collection effort. It provided the stimulus to do a more detailed investigation of systemic innovation implementation in interorganizational networks. In the second perspective described in Chapter 3, I focus my data collection effort on 26 design and construction organizations implementing 3D CAD. 3D CAD differs from the more process-oriented innovations I observed in Chapter 2. The evolution from 2D CAD to 3D CAD fundamentally changes the role interactions between design and construction firms; hence it is a systemic innovation. 3D CAD requires design and construction firms to evolve from the separate development of a 'printed set of plans' boundary object to the co-creation of a 'virtual model'. This paper asks the question *how firms in interorganizational networks implement technological change in boundary objects*.

Based on qualitative analysis of data collected from 13 design and 13 construction organizations, the paper contributes 14 key antecedents that contribute to the successful implementation of 3D CAD in design and construction networks. Comparing variances in response patterns for each key antecedent across designers and contractors I identify differing implementation perspectives between designers and contractors, as well as a set of shared perspectives on the implementation of 3D CAD. Finally, I group the antecedents into five thematic areas; regulative interface issues (*address issues of liability*, *address contractual constraints*), technology interface issues (*experiment with 3D CAD*, *address interoperability of technology*, and *work with firms using same software*), organization interface issues (*increase collaboration between firms*, *develop partnerships between firms*, *understand shared interests among firms*, and *cross-pollinate ideas across firms*), work interface issues (*redistribute work among firms*, *develop standards for interaction*, and *develop system understanding of project*), and change management issues (*obtain sufficient 3D CAD training* and *work with an external change agent*).

This paper takes previous research investigating the boundary object evolution from sketches to 2D CAD within design organizations (Henderson 1991, 1999) as its point of departure. It also leverages previous research not related to boundary objects on the implementation of 2D CAD within organizations (Manske and Wolf 1989, Robertson and Allen 1992, Salzman 1989) and the adoption (Harty 2005, Mitropoulos and Tatum 1999, Whyte et al. 1999) and implementation (Argyres 1999) of 3D CAD in networks. The paper in Chapter 3 extends Henderson's (1991, 1999) exploration of boundary object technological change within design organizations to the interorganizational level. Henderson (1991, 1999) identified organization and work interface issues accompanying boundary object technological change within design organizations. The work interface findings of this dissertation and Henderson's (1991, 1999) work are consistent with the findings of other 2D CAD implementation studies in design organizations (Manske and Wolf 1989, Robertson and Allen 1992, Salzman 1989). I extend Henderson's work by showing that similar work and organization interface issues arise across organizational boundaries when boundary object technological change impacts multiple specialist firms in interorganizational networks. I also show how these same interface issues magnify in scope when crossing organizational boundaries.

This paper also identifies a set of regulative and technology interface issues not observed in Henderson's studies of the evolution to 2D CAD (Henderson 1991, 1999). Technological changes that bring together organizations from disparate occupational fields to co-create a boundary object require firms to *address interoperability of* *technologies* at technology interfaces. Organizations in networks make independent technology purchase decisions; therefore, it is common that firms in a network operate different 3D CAD platforms which do not share electronic building information model files seamlessly. A common strategy to address interoperability issues is to *work with firms using the same software*. This finding is consistent with the finding of another investigation of 3D CAD implementation in defense aviation networks (Argyres 1999). Furthermore, since organizations are legally distinct, organizations in networks may need to *address issues of liability* and *address contractual constraints* to enact the necessary redistribution of work. This research extends previous research on boundary object technological change to introduce a set of regulative and technology interface issues that apply when implementing changes of this type in interorganizational networks.

Perspective 3: The Alignment of Innovations and Networks

Each of the three perspectives contained in this dissertation contribute to a fuller understanding of innovation in interorganizational networks. However, the third perspective presented in Chapter 4 contributes the most to developing a more complete understanding of innovation in interorganizational networks. Increasing my data set from the 26 design and construction organizations investigated in Chapter 3, I investigate 82 design and construction organizations. I expand the research questions from Chapters 2 and 3 to understand *how role interactions in interorganizational networks impact the diffusion outcomes and implementation processes for innovations in different countries*.

To explore the question, I conducted a cross-national investigation of three comparable innovations in 3D CAD diffusing through and being implemented by design and construction networks in the United States and Finland. The investigation leads to the introduction of a set of moderating constructs (*alignment*, *relational stability*, *interests*, *boundary strength*, and *agent for network-level change*). The constructs of *relational stability* (as *organizational variety*) and *boundary strength* were evident, though less elaborated, in the first perspective on systemic innovation presented in Chapter 2 of this dissertation (Taylor and Levitt 2004). However, this more detailed investigation of systemic innovation in interorganizational networks across two countries extends my previous work and contributes three new high level constructs relating to the diffusion and implementation of innovations in interorganizational networks; *alignment*, *interests*, and *agent for network-level change*. The set of five constructs provide the foundation for me to build a grounded two stage theoretical model for innovation in interorganizational networks.

The theoretical model I introduce in the paper accommodates conflicting perspectives in the literature on the impact of forming into interorganizational networks on innovation. Where some researchers contend that interorganizational networks are the locus for innovation (Powell et al. 1996, 1998), others find it to stagnate innovation (Lampel and Shamsie 2003). In the context of implementing 3D CAD innovations in design and construction networks, my model illustrates how some networks excel in their ability to adopt system level changes while others find the mutual adjustment required by such changes exceedingly difficult. In doing so, this research contributes an integrative theoretical innovation framework that is flexible enough to accommodate contrasting empirical evidence on innovation in interorganizational networks from the existing literature.

Recent research on interorganizational networks extends beyond national borders to consider global networks (Lam 1997, Chen 2003, Möller and Svahn 2004). This research focuses on understanding knowledge sharing in interorganizational collaborations between Asia and either North America or Europe (Lam 1997, Möller and Svahn 2004) or on the marshalling of and distribution of resources in international firm networks (Chen 2003). There is a lack of research systematically comparing network forms of organization in different countries. In this third perspective on innovation in interorganizational networks, I identify how the set of constructs relating to innovation implementation in networks vary between Finnish and United States construction industry networks. These constructs and the inductive model that emerged from them contribute to an improved understanding of how network forms of organization differ in differing countries with liberal vs. coordinated market economies, (Hall and Soskice 2001) and how differences in role relations impact the implementation and can explain diffusion outcomes for systemic innovations.

Chapter 6

Suggested Directions for Future Research

The research that investigated the three perspectives presented in this dissertation was exploratory in nature. It contains several limitations that should be addressed in future research on the subject of innovation in interorganizational networks. The findings are based on a limited set of cases. Validity and reliability of the qualitative data were optimized within the constraints of the case study research design. Nevertheless, further research should be undertaken to gather more quantitative data in support of these claims.

I attempted to access detailed diffusion data for the innovations investigated in the three perspectives in this dissertation. However, due to concerns over confidentiality the vendors were unwilling to share exact data on market penetration. This therefore represents a further limitation for this research. Future researchers should study detailed quantitative diffusion data both to refine our understanding of the impact of the *alignment* of innovations to networks on diffusion and to measure the impact of the constructs identified on market acceptance in cases where innovations and networks are *misaligned*. A carefully chosen set of cases would allow researchers to test the relative importance of, and potential interactions between, the set of mediating constructs.

Several design and construction networks in the United States overcame the impact of weak *relational stability* (or high *organizational variety* to use the terminology from the exploratory study in Chapter 2) through strategies of vertical integration. A promising direction for future research would be to investigate whether an extended contingency theory can be developed for interorganizational networks. Such a research effort would observe the change in organization of the network in the face of technological change in different institutional contexts.

Perhaps the weak *boundary strength*, the network sharing of *interests* and the *agent for network-level change* observed in Finnish networks would decrease the need for vertical integration strategies identified in the United States construction networks. When I asked design or construction firms in Finland whether they considered strategies of vertical integration they commented that such strategies were unnecessary. Future research should test whether such conjectures are valid. This set of extensions would add an innovation perspective to both contingency theory (Lawrence and Lorsch 1967, Thompson 1967) and transaction cost economics theory (Coase 1937, Williamson 1975) for predicting the relative advantages and costs of market vs. interorganizational networks vs. hierarchical governance of transactions in different macro-economic contexts.

An interesting direction for future research would be to consider the impact of industry network structures in different countries on the design and development of technological innovations. Technology firms could benefit from an understanding of networks, *work allocations* within networks, and values for the strength of the constructs identified in this dissertation to determine which markets are most attractive in designing their 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 also tailor their products and services to *align* their scope with the *allocation of work* in the network market structure that results in the largest addressable market.

In reviewing the literature on the various industries adopting the network form of organization, I identified some distinct differences between industries that adopted network forms of organization before 1950 and those that adopted the form more recently since 1990. This research focused on the design and construction industries which adopted the interorganizational network form of organization prior to 1950 (Maesel 1953, Stinchcombe 1959). It would be interesting in future research to conduct a similar investigation of an industry that adopted the network form of organization more recently to contrast the findings with those contained in this dissertation. This would improve our understanding of the impact of the maturity of product modularity and role interactions on the diffusion outcomes and implementation processes resulting from technological changes in interorganizational networks. As I stated in Chapter 1 of this dissertation, maturity of products and role interactions in interorganizational networks may also provide an opportunity for understanding differences in innovativeness and performance outcomes in published interorganizational network studies.

In this dissertation and in many interorganizational network studies, Eccles' (1981) work on *quasi-firms* is either central (Luke et al. 1989, Powell 1987, 1990) or referenced as a typical interorganizational network. However, I observe from United States Census Bureau (1997) reports (see Chapter 2) and in my *relational stability* findings (see Chapter 4), that construction industry networks appear to have changed significantly in the way firms relate to other firms in their network over the last 25 years. An interesting area for future research would be to conduct an affiliation network analysis of firm networks for the construction industry in the United States over time. This data could be correlated to innovation outcomes over the same period to investigate the impact of changing *relational stability* in networks over time on the ability for construction industry networks to adopt technological innovations.

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