Understanding and managing systemic innovation in project-based industries

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Abstract

Traditional industries (e.g., aerospace and pharmaceuticals) that once organized their activities into functional hierarchies are evolving into 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 proliferation of organizational forms emerging between market-based organizational interactions and hierarchical organizations as 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 outsourcing of specialized skills increases, product and process innovations with potential to improve overall productivity significantly (e.g., supply chain management, enterprise resource planning, or component prefabrication) often require multiple interdependent firms to change their processes. Although they may hold the promise of significant increases in productivity and profitability, data shows that these *systemic* innovations diffuse slowly in project-based industries. This research explores the structural mechanisms inherent in project-based forms of organization 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. 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 design focuses narrowly on innovations in residential building, though we seek to generalize our model to 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 U.S. residential homebuilding industry.
4. Introduce a proof-of-concept model for systemic innovation in project-based industries.

This paper concludes with a research agenda to improve our ability to understand, predict, and influence rates of diffusion for systemic innovations 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. Project-based forms of organization are also becoming prevalent in new and emerging industries (e.g., biotechnology and information technology). Innovation research to date, however, has largely been conducted in traditional, hierarchical organizations. When project-based industries are included in innovation studies, the analyses rarely meaningfully explore the differences in mechanisms and rates of innovation that emerge between traditional, hierarchical forms of organization and project-based forms of organization. This research proposes to explore these 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 of the construction industry in the United States (U.S.); 2003 revenues exceeded half of the $882-billion spent on construction (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 be a laggard adopter.

Systemic innovations requiring multiple companies to change in a coordinated fashion include recent advances in supply chain management, increasing use of enterprise resource planning, 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, they 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 systemic innovation diffusion. By gaining insight into the mechanisms that impact adoption of systemic innovations in project-based industries, we can begin to capture the productivity gains that manufacturing industries have achieved through broadly adopting systemic innovations.

In this paper, we apply the concepts of *incremental* and *systemic* innovations in the project-based industry context. We position our research in the body of research on innovation in project-based industries. This paper establishes with outcome evidence that systemic innovations diffuse more slowly than incremental innovations in the United States (U.S.) residential construction industry. We explore the process of systemic innovation diffusion through two case studies to reveal a set of constructs that provide the foundation for a proof-of-concept model for systemic innovation diffusion in project-based industries. We hope this explanatory proof-of-concept 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 U.S. 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 (e.g., the plumbing, mechanical, and electrical systems) 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 & 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 concluded that the move from hierarchical forms of organization to project-based organizations created “an evolutionary stagnation in the craft of making movies” (Lampel & Shamsie, 2003, 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 be created for diffusion of systemic innovations over time.

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 & Salter, 2000). Perhaps this derives from the fact that most innovation studies in the building industry have focused on *behavior of the firm* instead of the *structural characteristics of the market*. This paper addresses this call by proposing to explore the structural mechanisms that differentiate traditional, functionally organized industries from project-based industries affecting 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 at the market level on a population of firms' *ability* to adopt. This research tends to focus more on the structural characteristics of the adopting population. In 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.

Exhibit 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 in Exhibit 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.

Exhibit 1: Market-oriented Building Industry Innovation Literature Summary

Author	Research focus	Key findings
Arditi and Tangkar (1997)	Study of innovation rate in construction equipment over 30 years.	Finds that the number of new models increased from 1962-1992 and that all the innovations were incremental in nature.
Blackley and Shepard (1996)	Diffusion of incremental innovations among 417 homebuilders.	Finds that industry fragmentation does not impact adoption rate for incremental innovations.
DuBois and Gadde (2002)	General investigation of construction industry productivity and innovation.	Finds the industry to be loosely-coupled; therefore, concludes that diffusion is forestalled.
Gann, Wang, and Hawkins (1998); Gann and Salter (2000)	Investigates energy-efficient housing regulation's impact on innovation.	Finds that imposed regulations in the United Kingdom's (U.K.). building industry neither inhibits nor stimulates innovation.
	Interviews 30 construction firms to understand innovation in construction.	Finds that the discontinuous nature of construction leads to broken learning and feedback loops.
Lutzenhiser and Biggart (2003)	Energy efficiency diffusion in commercial building.	Finds that only incremental innovation is possible in the building industry due largely to fragmented nature of the industry.
Oster and Quigley (1977)	Impact of regulation on diffusion across four innovations in 1970.	Finds that the education level of building officials, the extent of unionization, and the size of firm affect diffusion.
Winch (1998)	General investigation of innovation in the British construction industry.	Suggests that relatively low rate of innovation may be due to structural features of industry that can enable simultaneously 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 et al. (1998) investigated the impact of industry regulations on the homebuilding industries in the U. S. and the U.K., respectively. In testing for a number of variables across four innovations, the Oster 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 et al*.,* in a study of the diffusion of energy efficiency in homebuilding, found that regulations in the U.K. neither inhibit nor stimulate the diffusion of energy efficiency.

- *Impact of Decentralized Industry Structure on Innovation*
  Citing the work of Karl 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. However, they find that "loose coupling could also forestall the spread of advantageous mutations" (DuBois & Gadde, 2002, 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 diffuse in the building industry.

> Our search identified three papers that explore innovations in the industry in order to understand the market-level structural mechanisms at work. Arditi and Tangkar (1997) explored innovations in construction equipment over a thirty-year period to understand the rate and types of innovations that diffuse in the construction industry. They found that innovations in heavy equipment were all incremental in nature but that the rate of introduction of new models, a proxy for innovation rate, had increased. Blackley and Shepard (1996) looked at innovations diffusing in a population of 417 homebuilders. The results of their analysis did not support the hypothesis that the fragmented industry structure reduces the diffusion rate for innovations. However, it should be noted that the Blackley and Shepard 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 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" (Lutzenhiser & Biggart, 2003, p. 3). In the final analysis, the Lutzenhiser research describes the industry actors as each having a "separate social world with its own logic, language, actors, interests and regulatory demands" (Lutzenhiser & Biggart, 2003, p. 47).

The 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 both in the amount and 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 on the impact of regulation 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 focuses on incremental innovations. Incremental innovations are those that reinforce the existing product or process and provide a measurable impact on productivity (e.g., transitioning from stick-built construction to the use of prefabricated wall trusses in homebuilding). 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 prefabricated subcomponent wall systems in homebuilding.

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. Henderson and Clark's research suggested that the linkage 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. Exhibit 2 illustrates the Henderson and Clark innovation framework and gives examples of building industry innovations for each category.

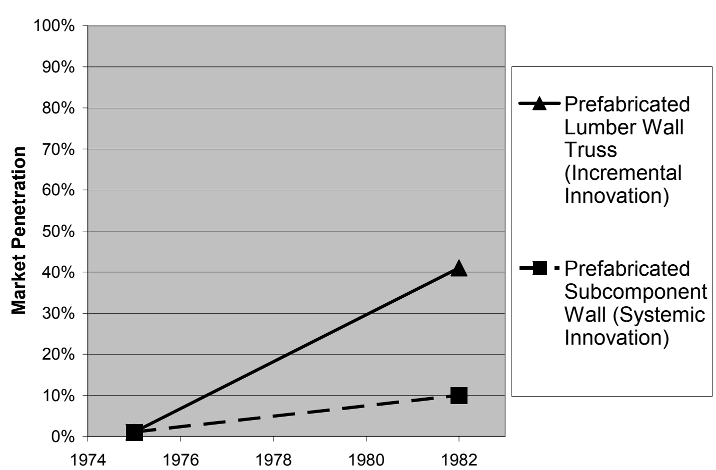
Exhibit 2: Innovation Framework Detailing Categories of Innovation Scope

		Core concept	
		Reinforced	**Overturned**
Linkage between core concepts & components	**Unchanged**	**Incremental innovation** *Example: Lumber wall truss frame replacing conventional stick-built lumber wall frame*	**Modular innovation** *Example: Extruded metal truss frame replacing conventional stick-built lumber wall frame*
	Changed	**Architectural (Systemic) innovation** *Example: Prefabricated wall frame with HVAC, plumbing & electrical components replacing conventional stick-built lumber wall frame*	**Radical innovation** *Example: Geodesic dome frame replacing conventional stick-built lumber wall frame*

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 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 systemic innovation diffusion.

To validate our conjecture that systemic innovations diffuse more slowly than incremental innovations, we sought data on building industry innovations. A U.S. Congress Office of Technology Assessment special report (1986) revealed some striking trends in systemic versus incremental innovations in the U.S. residential building industry. They reported that a wall truss incremental innovation in the lumber trade diffused rapidly through the U.S. construction industry over a seven-year period. However, they describe 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 Exhibit 3.

Exhibit 3: Comparison of Incremental & Systemic Innovation



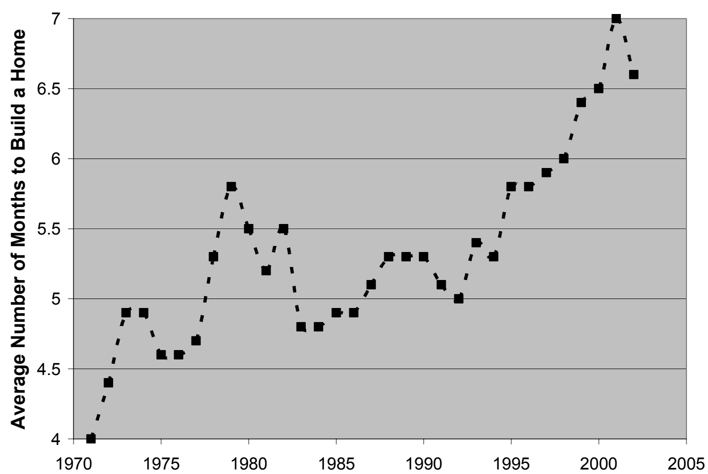
Clearly in this case, the incremental wall truss innovation diffused much more quickly than the systemic prefabricated subcomponent wall innovation. But we explored the issue further to understand what the impact of adopting incremental innovations more quickly than systemic innovations might be for the industry. Taking the roof truss as an example of an incremental innovation, we find in a National Association of Homebuilders Research Center report (O'Brien, Wakefield, & Beliveau, 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 housing industry had experienced an increase in construction duration over the last 30 years in the United States. 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 Exhibit 4). This is extraordinary given the fact that homes are routinely built in two days in trade show demonstrations (Caldeira, 2002b).

Exhibit 4: Average Duration of Single Family Home Construction in the U.S. (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% (U.S. Census Bureau, 1997), whereas the increase in the average project duration was about 15%. These findings were consistent enough that we began to suspect that the fragmented market structure might negatively affect systemic innovation diffusion. What is also interesting to note is that Blackley (1996), in a study of diffusion of incremental innovations across 417 homebuilders, found that diffusion was not impacted by fragmentation. This supports our assertion that regulation, decentralization, and fragmentation in the project-based industry structure impact systemic and incremental innovations differently.

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 single-family residential homebuilding in the United States. The goal of this case research was to develop a proof-of-concept explanatory model for 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

Our case research focused on two cases of systemic innovation in the single-family residential homebuilding industry in the United States. Both cases required multiple trade contractors to change their business processes while requiring little, if any, change in the actual product. One case was an innovation in supply chain management that focused on improving information and material flows between large builders and manufacturers for plumbing, electrical, and mechanical supplies. The second case was an innovation in wall construction that focused 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—that 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 waiting time 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 represented a significant impediment for the rapid diffusion of Supply Chain Innovators' innovation and 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. However, they found that the mechanical, electrical, and plumbing teams working on the projects could not effectively develop routines for their interdependent work activities impacted by the innovation.

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 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 United States. 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 U.S. 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 their national operation. However, the larger builder was unwilling to integrate the different trade groups into their 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 emerges. 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 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 the rate than 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 (e.g., plumbing, mechanical, electrical). One of the main research thrusts in market-oriented innovation studies in the building industry focuses on issues of regulation or innovation (Oster & Quigley, 1977; Gann et al., 1998). 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 they 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

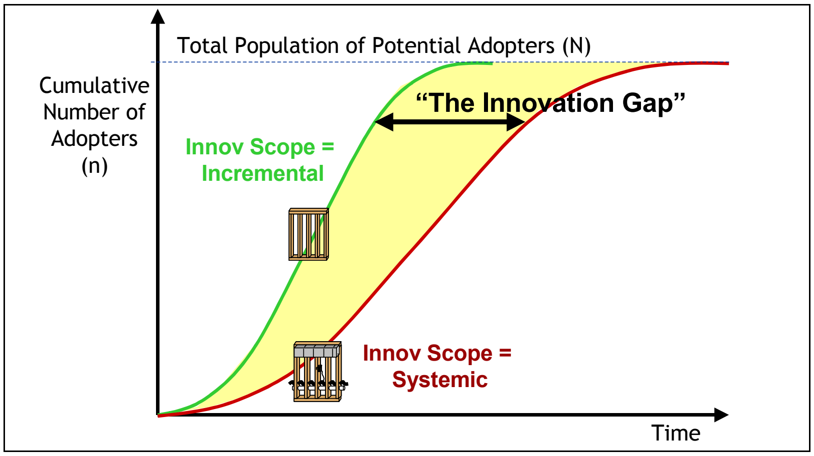
These four constructs break down the regulation, decentralization, and fragmentation structural concerns into mechanisms that can be researched and modeled. We consider a final construct, which becomes a new independent variable, called the *scope of the innovation*. We propose that the constructs described 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 Exhibit 5.

Exhibit 5 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 residential building industry in the United States. However, we anticipate similar effects in other project-based industries.

Exhibit 5: Diffusion S-Curve Illustrating the "Innovation Gap"



Several different modeling frameworks exist to describe diffusion based on 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 & 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 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 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 (Damanpour, 1991). 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:

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

Where;
- **N** = Total number of firms in 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. This work is also a first step toward extending the Bass 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:

- *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 inter-organizational 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 being impacted. The more specialist firms that an innovation spans, the more difficult it will be to develop the inter-organizational routines required to unlock the productivity benefits of the innovation. If there are firms that integrate the work of multiple specialist firms (e.g., an MEP contractor that does 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 on the diffusion of systemic innovations. Researchers should assess the extent to which the 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 for residential building in the United States 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, a comparison of systemic innovation diffusion in differing market structures with differing institutional contexts should be completed. 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 systemic innovations diffuse significantly more slowly than incremental innovations in the United States residential building industry. We further explore 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 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 introduced in this paper is a first step toward explaining the disparity in diffusion for incremental and systemic diffusion rates in project-based industries. We discussed several implications describing how project managers are impacted by systemic innovations and strategies for dealing with these difficulties.

Acknowledgements

Support for this research has been provided by a Stanford University Center for Integrated Facilities Engineering seed research grant. The authors also acknowledge the advice and helpful suggestions of Hans Björnsson, Steve Barley, and Bob Tatum.

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