Systemic Innovation of Complex One-Off Products:

The Case of Green Buildings

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Abstract

This paper examines the innovation of complex one-off products in heterogeneous, distributed systems. Unlike standard product development, which has received a lot of attention from researchers, the systems that produce complex, one-off products in mature industries lack many of the typical organizational features that researchers have deemed critical to product development success (e.g., team familiarity, frequent communication, strong leadership). In contrast, the complexity of these products requires a diverse knowledge base that is rarely found within a single firm. The one-off nature of products further requires improvisation and development by a distributed network of highly specialized teams. Project teams are thus often temporary and fluid, and often lack strong, centralized leadership. And because the product is complex, significant innovations in the end product require systemic shifts in the product architecture. In this study, our focus is to examine which organizational features facilitate systemic innovation in such complex, one-off products. Our key finding is that *firm integration* across specialists that have the highest levels of interdependence (i.e., ownership integration, and single contract for both design and construction) mitigates the knowledge and coordination problems induced by the introduction of systemic innovations into complex, one-off products. Our analyses are based on an original, hand-collected dataset of the design and construction of 112 energy-efficient "green" buildings in the U.S., combined with in-depth fieldwork.

Keywords: innovation; product development; unique, complex products; distributed systems, mature industries, horizontal integration, vertical integration.

New products are typically a fusion of new and existing knowledge (Iansiti 1995). Rarely does new product development, especially for custom-built projects, involve exclusively existing or exclusively new knowledge. More often development is achieved by taking an existing product, such as a building design, and modifying or adding to it in some new and potentially significant way. A typical modification is the integration of innovative components into the product (Chesbrough 2003; Iansiti 1995; Taylor 2010). For example, a building can be innovative to the extent that it incorporates innovative components such as energy management systems, grey water reuse systems, or highly efficient lighting fixtures. Successful integration of innovative components into products can bring significant competitive advantage for firms that develop them.

Much prior work has studied product development success (e.g., Atuahene-Gima and Li 2004; Brown and Eisenhardt 1995; Ernst 2002; Natter et al. 2001; Sheremata 2000; Taylor 2010). One key factor underlying success is careful internal organization including team familiarity, frequent internal communication, and strong project leadership (Brown and Eisenhardt 1995). Team familiarity increases psychological safety (Edmondson 1999), enables the transfer of tacit knowledge (Hansen 1999), and enhances coordination and learning (Weick and Roberts 1993; Katila and Ahuja 2002). Frequent internal (especially informal) communication breaks down functional barriers (Dougherty 1992), helps developers identify problems early and so yields enhanced performance. Strong leadership is critical to coordinate collaborative work and innovation (Davis and Eisenhardt 2011; Lawrence and Lorsch 1967).

While helpful to understand product development, the conclusions of prior work typically draw on analyses of complex products in mass production settings such as automobiles (Clark and Fujimoto 1991; Hayes et al. 1988), robots (Katila and Ahuja 2002), computers (Eisenhardt and Tabrizi 1995; Iansiti 1993, 1994), and telecommunication equipment (Phelps 2010). We consider these products complex because they involve a high number of components that interact in non-simple ways (Simon 1962), but they are not one-of-a-kind because they are often mass-produced. In this study, we define "one-off" to mean that each instance of the product is custom-made to some degree and thus differs from any other unit; that is, every unit of the product is developed separately with the attendant need for some improvisation. The development of complex products that are one-off, such as intelligent buildings, high-speed trains, nuclear power plants, hospitals, space-craft, and weapon-systems has received little attention from organization scholars.

The development and construction of complex one-off products is notoriously difficult. While complexity requires a diverse knowledge base that is rarely found within a single firm, one-off products require improvisation that is difficult to coordinate across firm boundaries. Nonetheless, because the diversity of knowledge that complexity requires is rarely found within the boundaries of a single firm (Hobday 1998, 2000; Hobday et al. 2000), these products are typically developed by networks of highly specialized firms. And because product development is one-off, a typical organizational arrangement for this in mature, and hence fragmented, industries is a distributed, heterogeneous network of highly specialized firms that work together temporarily (Bechky 2002, 2006; Boland et al. 2007; Goodman and Goodman 1976). These networks generally lack the organizational design elements that past research finds critical to product development success. For example, the temporary nature of these organizations implies that individuals have limited prior experience working together and, hence, limited familiarity with one another (Bechky 2006). Because of high specialization and low familiarity, internal communication is also infrequent (Dougherty 1992). Moreover, many networks exhibit weak project leadership and minimal centralized coordination. Therefore, in contrast to high-performing mass-produced product development projects that can exploit team familiarity, frequent internal communication, and strong project leadership to succeed, high-performing complex, one-off products are often characterized by temporal teams, infrequent communication, and resource-limited system integrators and must thus rely on other elements to succeed.

A few studies of complex, one-off products show that incremental improvements of these products (i.e. innovating on individual components) can be achieved by relying on external standards (Garud et al. 2002; Jain 2012) and shared institutional knowledge (Bechky 2002, 2006; Stinchcombe 1959), instead of relying on internal organizational design. Since such "autonomous innovations" (Teece 1996) have no effect on adjacent components or the overall product architecture, their inclusion in the product does not require new interface definitions or integration processes. Thus, they can be incorporated using existing industry standards (Langlois and Robertson 1992) and institutionalized knowledge about processes and role systems (Bechky 2002, 2006; Stinchcombe 1959). However, prior research does not effectively deal with integration of systemic innovations into complex, one-off products in the absence of a well-resourced system integrator (Ulrich 1995). Incorporating components that represent "systemic innovations" (Teece 1996) requires readjustment of adjacent components and/or the overall product architecture. Thus, industry standards and institutionalized knowledge are less helpful in integration—and adherence to standards that are now inappropriate can actually impede it. The gap we address in this study is how systemic innovations can be integrated in complex one-off products. We examine whether organizational design elements such as firm integration enable the inclusion of systemic innovations and thus increase product innovativeness.

Our dataset is 112 energy-efficient (aka "green") buildings in the U.S., combined with 50 interviews of building professionals totaling 90 hours. We chose this setting because energy-efficient buildings are particularly good examples of complex, one-off products. A building is highly complex because it contains hundreds of components (e.g., foundations, structure, windows, heating and air-conditioning, lighting) that are interconnected through an elaborate product architecture. Each building is one-off to accommodate the tremendous variety of possible site conditions including land and climate, possible building uses, owner aesthetic preferences, and state and local codes and regulations. Thus, no two buildings are ever designed or built exactly alike (Haas et al. 1999). A building also provides ample opportunities to include innovative components, thus providing rich variation in the data. Specifically, a variety of energy-efficient technologies were included in the buildings in our sample in the designers' quest to obtain certification by the Leadership in Energy and Environmental Design (LEED) voluntary certification program of the U.S. Green Building Council. Some of these technologies represent autonomous component innovations (e.g., daylight sensors) while others are systemic component innovations (e.g., direct digital control systems). We explore the effect of firm integration as a way to overcome the knowledge and coordination problems that *systemic component innovations* induce.

There are several contributions. Our study extends the literature on product development and innovation to complex one-off products. We describe how such products are produced regularly without team familiarity, frequent communication, or strong leadership from a well-resourced system integrator. Although our qualitative interviews highlight the importance of including systemic component innovations in order to attain high levels of the metric that is the goal of the innovation (i.e. in this case a high level of energy efficiency), we find that, consistent with our predictions, systemic component innovations have in general a low probability of inclusion in buildings. However, firms can integrate systemic component innovations into unique, complex products more effectively through extending organizational boundaries by horizontal and vertical integration of the supply chain, and consequently develop more innovative end products that provide higher value to their clients.

BUILDING CONSTRUCTION AS RESEARCH SETTING

The design and construction of energy-efficient and other complex buildings provides an excellent research setting. Energy-efficient buildings are both complex and one-of-a-kind (Gann and Salter 2000).

Complex, one-off products

Complexity refers to the number of components that make up the products and their interactions. Following Simon (1962), we define products as complex if they are made up of a large number of components that interact in non-simple ways-e.g., they are connected through elaborate product architectures and design rules (Baldwin and Clark 2000). The level of complexity is a function of the number of components, the inter-relatedness of the components, the number of possible design choices, the elaborateness of the product architecture, the variety of material and information inputs, and the breadth and depth of knowledge and skills that inputs require (Hobday 2000). Energy-efficient buildings are extremely complex with thousands of interrelated components and subcomponents, many of which are often tailored to particular needs. Their complexity requires a wide breadth of knowledge in multiple domains that correspond to components. Further, the complexity of the components themselves necessitates deep knowledge within each domain.

One-off refers to each unit of the product being distinct to some extent from other units. In other words, one-off products involve some degree of customization, and cannot be mass produced. Instead, individual units of the product are developed and produced as one-off products by a network of hundreds of specialized firms, and no two buildings are typically built exactly the same (Haas et al. 1999).[1] Although one-off and complexity are two distinct features, they affect one another. For example, increasing a product's uniqueness may increase its complexity, but not always. If the increased uniqueness does not increase the number of components or alter

[1] Not all complex products are one-off, and not all one-off products are complex. For example, a new model flight simulator is a complex product (Hobday 2000), but it is not one-of-a-kind. A simulator is generally made up of standardized components, and several identical simulators can be produced. On the other hand, a piece of designer jewelry is one-of-a-kind, but it is not a complex product by our definition.

their interactions, complexity remains the same. The latter has been called “assemble to order.” An example is a unique configuration of a personal computer whose screen size and resolution, processor, kind and amount of system and persistent memory, etc. can be varied in a “plug and play” fashion, based on the PC standards that IBM promulgated in the early 1980s, and which remain largely in effect for both Windows-compatible computers and Mac OS computers today. In contrast a building containing one or more systemic innovations is a complex artifact that must be engineered and manufactured to order–not simply assembled out of standard components–since the innovation will not be “plug-and-play.”

Building design and construction networks of architects, engineers, and contractors serve as good models for the distributed, heterogeneous systems that are increasingly common in today's economy (Boland et al. 2007). Like other complex one-off products, the design and production of buildings requires an extensive amount of domain-specific knowledge. In order to deal with this significant knowledge requirement, individuals and firms within the industry have fragmented horizontally into separate trade crafts (Eccles 1981a, b) and vertically into different stages in a project's life cycle (i.e., project shaping, design, construction, commissioning, operations and maintenance). Firms in the construction industry tend to specialize in one trade and one vertical phase. Although some firms have multiple specialties, the vast majority produce just a single type of component and are experts at only one trade or a small number of trades required to produce their component. Further, the composition of project teams is typically selected by competitive bidding at the component level. This tends to shift the mix of participants dramatically from project to project (Dubois and Gadde 2002; Taylor and Levitt 2007). Shifting team composition is referred to as longitudinal fragmentation (Fergusson 1993). Taken together, the three-way fragmentation of the U.S. building industry results in distributed, heterogeneous, fluid project membership with minimal or no familiarity. In fact, on any given construction project, most tasks are subcontracted in order to fill the knowledge gaps that the main design firm and the general contractor lack. Firms come in and out over the duration of projects as needed to fill their particular roles and then depart.

Although, on paper, general contractors are considered project coordinators, in reality they provide a very thin layer of coordination (Sheffer 2011). Further, communication among project firms is minimal. Instead, each player knows exactly what their role is, when they are to fulfill that role, and how they need to do so. This is made possible by high-level *industry standards* and related industry-wide *institutional knowledge*, as is the case in other complex one-off products. Construction is one of the oldest and most heavily regulated industries, perhaps comparable only to pharmaceuticals with its host of safety regulations. Standards and codes are developed and maintained by national, state, and local organizations, and are enacted at the state and local levels (NAHB 2010). Set to ensure public safety, codes and standards essentially formalize the dominant design that has emerged in construction. Like design rules in other industries (Baldwin and Clark 2000), they specify the overall architecture by which components are integrated, the interfaces between components, and the integration process. As such, standards serve as an embedded coordination mechanism (Stinchcombe 1959).

In addition to standards, a large amount of institutional knowledge is shared among industry players. New industry players are socialized through craft trade unions (Stinchcombe 1959). These unions have clear jurisdictions within which they set professional standards, provide technical training to workers, enforce preferential hiring rights to its members, define what constitutes legitimate communications and procedures, and determine the division of work. Members of a craft institution have shared sense-making and collective understandings of the roles, expectations, and processes within their crafts and act with their own local logic (Boland 2003; Boland et al. 2007). In fact, the "professionalization of the labor force in the construction industry serves the same functions as bureaucratic administration in mass production industries" (Stinchcombe 1959). In sum, craft institutions dictate the roles of all industry players, and the extensive codes and standards dictate the processes by which specific components can be integrated into a completed product. Thus, subcontractors on a construction project coordinate themselves by following well-established procedures that are enshrined by their respective craft institutions, and general contractors need only provide very minimal coordination. Even in the parts of the industry that are now nonunion, all of the above characteristics apply, aside from enforcement of preferential hiring and strict jurisdictional boundaries between trades. In fact many of these workers were trained in union apprenticeship programs and previously worked as union workers.

Innovativeness of complex, one-off products

We conceive of a building's design and construction as a product development project with the building itself as the final product. The final product can vary in its innovativeness, e.g., in its use of innovative components to achieve a high level of energy efficiency. Innovativeness is a function of building design as well as inclusion and successful integration of innovative technologies.[2] Examples of energy-efficient technologies are high efficiency light bulbs, radiant floor heating, and intelligent building management systems. The more energy-efficient technologies are included and the better they are integrated with one another, the higher the energy performance and the more innovative the building is.

The basic value chain for a building comprises of the following steps: planning (project-shaping and financial feasibility), design, construction, commissioning, operations and maintenance. In principal, technology decisions should be made in the planning and design phases. Technology implementation should take place in the construction phase. However our interviewees confirmed that the need to customize each building to some degree results in modifications in the construction processes, which "require workers to go through a learning curve at the beginning stages of each project activity" (Haas et al. 1999). Once all the details are specified, the thousands of building components, each comprised of many subcomponents that are made up of different possible materials, are installed by hundreds of workers from a plethora of professional specializations.

Prior work and our qualitative interviews reveal that adoption decisions of innovations in building projects are nuanced and complex. Given the complexity of buildings, most owners are not knowledgeable enough to be able to decide on all technologies on their own.[3] Instead, they rely on design firms (architects, and engineering consultants) and construction firms to establish which technologies are available and recommended. Therefore, building professionals have a large impact on the adoption decisions of owners.

HYPOTHESES

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[2] In a study of the adoption of an innovative new method (digital 3-D representations) by a highly creative architectural firm (Gehry Partners), Boland and colleagues (2007) found that the decision to include the innovation triggered wakes of innovation throughout the entire project network, leading to some of the most innovative and famous buildings in the world. The inclusion of 3-D representations created new trading zones and encouraged new interactions among professionals across communities in the heterogeneous and distributed project teams. This particular scenario, however, is quite unusual in distributed, heterogeneous systems such as building construction projects. Frank Gehry is world-famous for his unique building designs, and the various firms that work on his projects are likely to be forward-thinking as well. In this paper, in contrast, we study a larger stock of buildings to examine the likelihood that various types of innovations are included in buildings. Thus, the process of how component technologies are selected deserves a close examination.

[3] At first, it appears as if decisions on which technological innovations to incorporate into buildings are made by building owners. Firms chosen to design and construct the building, in this scenario, must respond to exogenous innovations that are "forced" upon them by owners. If this were the case, adoption decisions should be based on straightforward cost/benefit analyses or other owner preferences without taking into account whether an innovation is localized or systemic, and should be unaffected by the risk of reputational damage. Some sophisticated real estate developers do have the in-house expertise to make these decisions, but this is the exception, not the rule.

Organizational challenges of developing innovative, complex one-off products

The combination of complexity and one-off nature creates special challenges for product development. As noted above, while complexity requires a diverse knowledge base that is rarely found within a single firm, one-off products require improvisation that is difficult to coordinate across firm boundaries. These products are thus most often developed and produced in one-off projects by distributed, heterogeneous networks of specialized firms that come together temporarily (Bechky 2002, 2006). The boundaries of these temporary product development organizations are porous, and firms come and go during the course of a single project.

The implication of the temporary nature of the product development projects is that actors that come together to develop these products may not have worked together before. Moreover, because product development teams need a diverse knowledge base in order to deal effectively with complexity, the developers themselves come from diverse specializations. The diversity of specializations in turn poses yet another challenge to effective exchanges among product development teams, as actors that belong to different "thought worlds" tend to have difficulties understanding, communicating, and relating to one another (Dougherty 1992) and group cohesiveness is low (Keller 2001).

Finally, many product development projects are done without strong leaders (Sheffer 2011). In each project, one firm generally serves the role of a lead coordinator or *system integrator*. However, that firm does not always have enough power, knowledge, resources, or time to coordinate the multitude of firms that come and go during the product development process. In construction, for example, general contractors are assumed to play the role of central coordinators. However, they merely provide a very thin layer of coordination, and the network of subcontractors on a construction project essentially coordinate themselves (Sheffer 2011). On a large building project site with hundreds of workers at any given time, only a handful of dedicated workers—typically a project superintendent and a handful of project engineers and administrators located in an adjacent office trailer—work for the general contractor, with the remaining hundreds of craft workers and their foremen and/or superintendents working for dozens or even hundreds of subcontractors. Moreover, these projects are frequently awarded to general contractors by competitive bidding. Many of the same subcontract bids are available to all of the general contractors bidding the project, so the resulting profit margins of general contractors are extremely low, as compared to those of the subcontractors who employ the bulk of the labor and equipment on the project, leaving general contractors unable to invest additional resources into coordination beyond the standard thin coordination layer described above.

Even highly sophisticated and well-resourced system integrators can encounter challenges when attempting to innovate complex products systemically. Boeing introduced two key systemic innovations in its Boeing 787 “Dreamliner” airplane: fiber composite materials in place of titanium alloys for body parts; and fly-by-wire controls in place of pneumatic controls. As a direct result of these two changes, they encountered numerous, unplanned and extremely costly manufacturing and operations problems, ranging from shortages of connectors for the body parts during assembly to battery fires during early operations, that delayed production and sales of the Dreamliner by years (Kotha and Srikanth 2013).

Given that product development teams of complex one-off products lack the features that scholars have deemed to be critical to product development success, including team familiarity, frequent communications, and strong leadership (Brown and Eisenhardt 1995), a natural question to ask is, how are complex one-off products developed*?* In particular, we seek to explore in this paper how innovative the products can be given the inherent difficulties of innovation of complex products.

Innovativeness of complex products is generally manifested through the incorporation of innovative components. These innovations can vary both in their degree and type of change that a component innovation involves (Henderson and Clark 1990; Tushman and Anderson 1986; Tyre and Hauptman 1992). The degree refers to the innovation's technical novelty, whereas the type of change refers to the innovation's compatibility with the product architecture and the established system of common designs, architectures, roles, processes and practices within the industry. Incompatibility with the established system, referred to as "systemic shift" (Tyre and Hauptman 1992), is especially critical in complex one-off products. Along this dimension, we can distinguish between two types of innovations: autonomous and systemic (Teece 1996).

Autonomous component innovations are compatible with the established system and can be included without modifying other components. They have no effect on the overall product architecture. Thus, the innovative component in a sense "stands alone". Examples of autonomous component innovations in buildings are high efficiency light bulbs that fit into the same light sockets as incandescent bulbs, CO^2 monitoring equipment with interfaces and installation that are essentially the same as those for smoke detectors, or infraredactuated faucets or toilets that are designed and installed in the same way as manually-controlled faucets and toilets.

In contrast, the introduction of *systemic component innovations* into the system involves significant readjustment to other parts of the system (Teece 1996). Examples of systemic component innovations in buildings are radiant floor heating, intelligent building management systems, chilled beams, and ground source heat pumps. Each of these systemic innovations involved extensive deviations from industry standards and institutionalized knowledge about roles and responsibilities, work processes, materials, and component interdependence at the time of this study. For example, radiant floor heating is an energy-efficient heating system based on radiant heat transfer instead of the standard forced-air heating. Installing it involves an extensive network of pipes underneath a floor and, hence, a departure from standard floor construction processes. On the design side, radiant heating has many implications for adjacent components, such as the choice of flooring (e.g., carpeting is generally discouraged; wood can be selected, but should be laminated rather than solid wood and ceramic tile is the most effective choice of flooring; etc.). On the construction side, the sequence of activities performed by the various subcontractors changes in several ways. For example, mechanical workers need to lay the piping before the floor concrete is poured by employees of the concrete subcontractor.

Integrating any kind of component innovation into products can be challenging and is likely to generate difficulties. Systemic component innovations are particularly challenging because they alter interfaces between components or the overall product architecture, and they can alter assembly processes and sequences. In a classic study, Henderson and Clark (1990) illustrate such difficulties within a firm in the semiconductor photolithographic alignment equipment industry. Further, when unique, complex products are developed by a temporary and shifting network of firms, the difficulties are exacerbated.

There are two primary challenges associated with the introduction of systemic component innovations into products in temporary networks. The first challenge is a *coordination challenge*. Absent the introduction of the systemic innovation, firms coordinate their actions by adhering to industry standards and shared understandings about roles and processes. However, systemic innovations require these firms to redefine roles, relationships and mental models (Henderson and Clark 1990). These firms need to alter their work processes in order to coordinate the integration of the component innovation. Moreover, some firms that were previously independent have now become interdependent and need to learn new ways of working together. Doing so across firm boundaries and without strong leadership to dictate change and direct actions is difficult and could result in confusion.

The second challenge is a *knowledge challenge*. Systemic innovations require multiple firms to accumulate new systemic knowledge, which is exceedingly difficult. Because the official lead firm in many industries such as construction often lack sufficient profit margins to provide substantial coordination (Sheffer 2011), it may lack the resources to set up training programs and knowledge management systems. And, not all systemic knowledge is codified, which makes its accumulation slow and difficult (Grant 1996; Nonaka 1994; Zander and Kogut 1995). The combination of firm heterogeneity and actors' lack of shared history also creates difficulties developing trust and a collective team identity, both of which enable learning and knowledge sharing (Barki and Pinsonneault 2005; Dougherty 1992; Levin and Cross 2004; Levin et al. 2002; Van Der Vegt and Bunderson 2005). Finally, the temporary nature of product development for unique, complex products results in discontinuous learning (Gann and Salter 2000), so even when some actors learn, the knowledge is slow to diffuse throughout the industry resulting in missing knowledge for some actors in subsequent project development projects.

Given the coordination and knowledge challenges, the inclusion of systemic component innovations is challenging. In contrast, autonomous component innovations do not lead to extra coordination challenges between firms because no additional interdependencies are added to the product. Product developers can continue to rely on extant standards and shared understandings about roles and processes. Autonomous component innovations do require new knowledge to be accumulated, but unlike systemic innovations, the knowledge is domain-specific and thus limited to specific firms. Thus, the management of the affected firms can set up their own training programs and knowledge management systems. Further, tacit knowledge is easier to accumulate within a firm (Argyres 1996; Christensen et al. 2002; Wolter and Veloso 2008). Moreover, developing trust and a collective identity is easier within a firm than across firm boundaries, both of which facilitate learning. Finally, in spite of the discontinuous nature of the development of unique, complex products which hinders the accumulation of knowledge at the industry level, participating firms can individually accumulate domain-specific knowledge over time (Hobday 2000).

In sum, innovation in complex one-off products is straightforward to the extent that the innovative components conform to extant standards and do not require the accumulation of new systemic knowledge. However, we hypothesize that due to the coordination and knowledge challenges that systemic component innovations introduce, they are less likely to be included in complex one-off products than autonomous component innovations.

> *Hypothesis 1 (H1): Systemic component innovations have a lower probably of being included in complex one-off products than autonomous component innovations.*

Firm Integration as a Solution to Developing Innovative Products

In many cases, significant levels of overall performance improvement can only be achieved by taking a whole-system approach rather than attempting piecemeal improvements (Ulrich 1995). In other words, systemic component innovations may hold greater promise for overall product improvement than autonomous component innovations. If our predictions are accurate and systemic component innovations are unlikely to be incorporated into complex one-off products, then the current development model is not effective. The model only permits limited innovation, leaving system-wide breakthroughs unlikely. A natural question to ask is, how can the likelihood of successful integration of systemic component innovations into complex one-off products be increased?

Because the two main barriers to systemic innovations are coordination and knowledge challenges, a possible answer is firm integration. By integrating parts of the supply chain, both the coordination and knowledge challenges are more likely to be overcome. Coordination is easier and less costly within a firm than across firm boundaries (Williamson 1981). Firm integration aligns the interests of otherwise disparate players. In integrated firms, management can serve as a coordinator among specialized divisions. Centralized management can mandate the change, set up training programs, and dictate the use of knowledge management technologies.

Integrated firms can also overcome the knowledge challenges more readily than specialized firms. There are four reasons. The first is that knowledge is easier to accumulate within than across firm boundaries. According to the knowledge-based view of the firm (Grant 1996), firms internalize activities in technologically-uncertain, innovative environments because they are better able to coordinate activities ex ante (Conner and Prahalad 1996; Kogut and Zander 1992). Further, when high degrees of tacit knowledge are involved, firms again outcompete markets: research has shown that tacit knowledge is more easily appropriated and transferred within firm boundaries (Argyres 1996; Christensen et al. 2002; Wolter and Veloso 2008). Second, integrated firms have a broader knowledge base and thus greater absorptive capacity (Cohen and Levinthal 1990). The broader knowledge base helps integrated firms better understand the system-wide effects that systemic innovations bring about. They are therefore better able to accumulate relevant knowledge, and thus more likely to adopt and diffuse systemic innovations. Third, the one-off nature of the development and production of products results in discontinuous learning and broken feedback loops (Gann and Salter 2000). Firm integration increases the likelihood that some project members will have experience working together and can learn together. Given the systemic shift induced by systemic innovations, learning together is critical. Fourth, integration may help bridge the abyss between silos of professions (Dougherty 1992) and foster trust development which in turn increases knowledge sharing. In sum, we hypothesize that firm integration is a better organizational arrangement for the inclusion of systemic component innovations because it helps network firms overcome the coordination and knowledge challenges induced by systemic innovations.

Hypothesis 2 (H2): Firm integration increases the likelihood of inclusion of systemic but not autonomous component innovations in complex one-off products.

METHODS

Sample and data

Our quantitative sample is drawn from the population of energy-efficient buildings certified by the Leadership and Environmental Design (LEED) program of the U.S. Green Building Council. LEED is the most common green building certification system in the U.S. today, and one of the most common systems in the world (France 2007; Potbhare et al. 2009; Williams 2010). It is a system available to builders, designers, and architects who wish to identify their buildings as high performing on environmental and energy dimensions. Since LEED's creation by the U.S. Green Building Council in August 1998, almost 40,000 building projects have registered their intent to be certified and nearly 9,000 have already obtained certification (USGBC 2011). LEED evaluates a building's environmental design and offers multiple levels of certification (certified, silver, gold, or platinum) based on the number of environmental elements a building adopts. Each element corresponds to a particular credit and is awarded a specific number of points. The credits and points structure of the LEED system provides a clear measure of component integration. Points are awarded only once documentation has been submitted to prove that the requirements of particular credits were met. Thus, technology inclusion can accurately be deciphered by examining LEED scorecards and project descriptions of the buildings in the sample.

Our sample consists of 112 energy-efficient buildings certified by the Leadership in Energy and Environmental Design (LEED) program of the U.S. Green Building Council between 2000 to 2009. We explore building innovation by examining the likelihood of inclusion of 23 different technologies – eleven autonomous and twelve systemic component innovations. The 23 technologies and 112 buildings yield 2,576 building-technology observations. Each observation represents an opportunity to include a component innovation in a building. Data about the buildings were obtained from a database of LEED buildings maintained by the U.S. Green Building Council (USGBC 2010). The database contains detailed case studies and LEED scorecards for 130 buildings. In order to focus on comparable buildings, we chose to focus on U.S. buildings that were certified under the most common LEED system (LEED for new construction and major renovations, version 2). Thus, we eliminated five buildings because they were outside the U.S. and thirteen because they were certified under a different LEED system.

The final sample consisted of 112 newly constructed U.S. buildings. Although there are thousands of buildings in the population, our sample of 112 is particularly comparable in terms of energy efficiency and environmentalism goals. Second, the buildings vary in terms of geographies, building types and sizes, building ownership, and procurement methods, increasing generalizability. A third of the buildings are commercial office buildings, a quarter are educational buildings, and the remaining represent a wide variety of uses. Building ownership is approximately split between government, non-profit, and profit organizations. Building sizes range from approximately 3,000 to 1.5 million square feet (mean= 120,000ft^2, SD= 190,000ft^2). Project costs range from $350 thousand to $165 million (mean= $26 million, SD= $33 million). These characteristics increase the generalizability of the findings.

We supplement our quantitative data with in-depth field work, including visits to construction sites and 50 interviews totaling 90 hours with a variety of building industry experts. The interviews included both open-ended discussions about innovations in the construction industry and technical discussions about the technologies in the study. The experts we interviewed were architects, project managers, engineers, building technology scientists, LEED professionals, estimators, operations managers, and executives. Our interviewees worked at a variety of firms, including large general contractors, small specialty "green" contractors, construction and energy-efficiency consultancies, and a variety of firms that specialized in engineering, architectural design, risk management, and construction financing.

Measures

Dependent variable. The main dependent variable was *inclusion* of an energy-efficiency-increasing component technology into a building. There were 23 possible component technologies. Examples are fixture sensors to supply water only when needed, high efficiency lighting such as LED bulbs to increase luminescence with less energy, biomass to generate power through the combustion of organic plant material, building monitoring systems to digitally control and optimize energy performance, and ground source heat pumps to store and retrieve heat from ground sources. With 112 buildings and 23 component technologies, there are 2,576 possible occasions for technologies to be included. We used a binary variable that was coded as *one* when a particular technology was included in a building, and *zero* otherwise. The credits and points structure of the LEED system provides a reliable measure of building technology inclusion. Points are awarded only once documentation has been submitted to prove that the requirements of particular credits were met. To ensure a robust measure, we cross-checked the list of technologies generated from project descriptions with the third-party verification provided by the LEED scorecards. To make sure that no technology was missed or miscoded, each project description and LEED scorecard was coded by three independent coders in our research team who were asked to list all the technologies that were included in each project. Of all possible inclusion opportunities, innovative component technologies were included 28% of the time (or 721 times out of 2,576).

Independent variables. Two independent variables were included: autonomous vs. systemic innovation and degree of firm integration. A technology was considered autonomous if it did not involve any alteration to interfaces with adjacent components or modifications in the design or installation process. A technology was considered systemic if the interfaces were changed, the design or installation processes were changed, or both. *Systemic innovation* was coded as one when a technology induced a change in the overall product architecture and adjacent components. Each technology was coded by eight building industry professionals as an *autonomous component innovation* (=0) or a *systemic component innovation* (=1) in comparison to the most standard technological alternative. We chose to focus on Mechanical, electrical and plumbing (MEP)-related technologies because they play a central role in buildings overall, making up approximately 40-60% of total project costs, and in energy efficiency in particular (Khanzode 2010).

The list of relevant technologies was derived as follows: 1. The researchers assembled from the case studies a list of all the technologies that were included in the buildings. 2. Technologies that were *not* related to mechanical, electrical, and plumbing (MEP) systems were eliminated. 3. We eliminated from the list technologies that could not co-exist in the same building or were too specialized only to particular building types to make sure that all technologies could have been included in any building in our sample. The resulting list of technologies consisted of 23 technologies. Eight expert building industry professionals subsequently coded them into 11 autonomous vs. 12 systemic ones. Examples of autonomous component innovations are daylight sensors, high efficiency appliances, individual thermostat controls, operable windows, and variable air volume systems. Examples of systemic component innovations are biomass, digital building monitoring system, chilled beam, and underfloor air distribution.

The second independent variable is *firm integration*. Each building project was coded as having a low, medium, or high level of firm integration based on a collapsed two-by-two table of two integration indicators. The first is *horizontal ownership integration* of mechanical, electrical, and plumbing (MEP) firms. Prior research shows that ownership integration positively affects performance, even if only modest levels of interaction exist between functional divisions (Fang et al. 2010). Horizontal ownership integration among MEP firms was discerned from the list of the key project participants in the detailed project descriptions. Firms were considered as integrated when the mechanical, electrical, and plumbing engineers worked at the same firm, and not integrated when the mechanical, electrical, and plumbing engineers came from three separate firms. The second indicator of firm integration is *building procurement method* as a proxy for vertical integration. Projects procured with the traditional design-bid-build (D-B-B) approach in which an owner has separate design and construction contracts were considered not integrated. Projects procured with the more vertically integrated design-build (D-B) approach in which an owner has a single contract with an entity responsible for both design and construction were considered integrated. Using these two indicators of horizontal and vertical integration, we constructed a three-level measure of integration. Project with *low integration* were those with neither vertical, nor horizontal integration, and were coded as *one*. Projects with *medium integration* were those with only one type of integration, either vertical or horizontal, and were coded as *two*. Projects with *high integration* were those with both vertical and horizontal integration, and were coded as *three*. We chose to combine the two medium categories because our sample size does not allow us to disentangle them. Firm integration information was missing for many of the case studies, but we were able to test the firm integration hypothesis on a subset of the data that contained the firm information (23 buildings, yielding 528 building-technology observations). There were no statistical differences between the projects for which firm integration data was available *vs.* for those for which it was not.

Control variables. Several control variables were included to control for other factors that may influence technology decisions. We controlled for *technology costs*, measured as the added capital cost over the most common alternative technology in dollars per square foot of building space, because our interviewees mentioned first cost as a significant factor in technology adoption decisions. Cost data were derived from two industry experts specializing in cost estimations and green buildings. Costs were adjusted for inflation and individual changes in technology prices over the seven-year period that the buildings registered with LEED (2000-2007).

We also controlled for *registration year* with LEED because market fluctuations have a large impact on buildings and the construction industry more generally. We chose to focus on the year that projects registered with LEED instead of the year that they were certified because background interviews revealed that most technology decisions are made around the registration time rather than the certification time.

We also controlled for *owner type*. We distinguished between for-profit organizations coded as one and non-profit or government owners coded as zero. The rationale was that although professionals recommend particular building designs or components, owners have the final say in what technologies are included in buildings. We distinguished between for-profit *vs.* non-profit owners because for-profit owners generally have more resources and may include more technologies in their buildings. Moreover, for-profit owners may include more energy-efficient elements as a marketing tool to present themselves as "green" (Corbett and Muthulingam 2007) or to save on operating expenses later on.

We controlled for the *size* of the MEP firms, which are the firms that need to design and install the energy-efficient technologies in our sample. Firms with up to thirty employees were considered *small*, and coded as one. Firms with thirty one to one hundred employees were considered *medium*, and coded as two. Firms with over a hundred employees were considered *large*, and coded as three. When the mechanical, electrical, and plumbing functions were not integrated and three separate firms provided them, we took the average of the firms' sizes.

We used a dummy variable to code whether the MEP firms list sustainability or innovation as their *core values*. The rationale is that firms that state sustainability and/or innovation is a core value may be more likely to include innovations related to sustainability in their designs. Although these decisions are ultimately an owner's choice, engineers could influence those decisions and convince owners and project managers of the merits of particular technologies.

We controlled for the *LEED score*, which is based on the number of environmental elements that a building includes. We included it in order to make sure that observed effects are not simply due to attempts to achieve particular LEED levels, and that innovation type and firm integration have an effect over and above the score.

Analytical approach

We used GEE logistic regression to test the probability that a component technology will be included in a building. Each of the 23 technologies can be included in any of the 112 building projects, so there are 2,576 inclusion opportunities. Since in each opportunity a technology was either included or not, we used binary logistic regression. Given the nested structure of the data of multiple technologies per project, we use

Generalized Estimating Equations (GEE) regression method. The GEE method controls for subject-level heterogeneity by accounting for the autocorrelation among the multiple observations per subject (Liang and Zeger 1986) and is therefore an appropriate method for data with multiple or repeated measures for each subject. In our sample, we have multiple observations of each building project. We assumed an independent working correlation matrix and used a robust estimator covariance matrix. We centered the variables to test interactions. To test each model's fit, we rely on Pan's (2001) quasi-likelihood under the independence (QIC) model criterion. It is an alternative to Akaike's information criterion that is widely used for model selection in general linear models and is inapplicable for GEE (Pan 2001). Lower QIC score indicates a better model fit.

RESULTS

Table 1 includes descriptive statistics and correlations for the variables. On average, component technologies were incorporated into buildings 28% of the time. The independent variables have a high degree of variance and low correlations.

--- Table 1 about here ---

We test the second hypothesis on a subset of our data (n=528). In order to check the robustness of the results of the small sample, we test the first hypothesis on the entire sample (n= 2576) and compare the results to those obtained with the reduced sample. The results are the same. Thus, in Table 2 we report the results for both hypotheses using the reduced sample.

--- Table 2 about here ---

The first model in the regression table includes only controls. As expected, costs are negatively related to inclusion. The more expensive a component technology is, the less likely it is to be included in a building. For-profit organizations include more innovations in buildings they own than non-profit owners. LEED score, year, firm size, and firm core values are not significantly related to inclusion. Model 2 introduces the systemic innovation variable into the equation. The negative and highly significant coefficient for systemic innovation ($\beta=-1.02$, $p<.001$) provides a strong support for the first hypothesis. Systemic technologies have a lower probability of being included, even after accounting for technology costs, LEED score, owner type, and year.

Further, a comparison of the coefficients of all the predictors in the model reveals that systemic innovation has the greatest effect on the probability of inclusion.

Model 3 introduces the main effect for firm integration. Since this variable is a factor, two variables were entered into the model. The first is high firm integration as compared to low, and the second is medium firm integration as compared to low. Both failed to achieve statistical significance. In other words, firm integration does not significantly affect the probability of technology inclusion. Further, the QIC score is essentially the same in models 2 and 3, indicating that adding the main effect of firm integration did not improve the model. Model 4 includes the interaction terms between systemic shift and high and medium firm integration. Both are positive and significant. The non-significant main effects for firm integration but the positive and significant interaction terms confirm the second hypothesis. Firm integration does not have a general effect on technology inclusion; however, it increases the likelihood of inclusion of systemic innovations, but not autonomous. The coefficient for high firm integration ($\beta=1.34$, $p<.01$) is larger than the coefficient for medium firm integration ($\beta=.84$, $p<.05$), indicating that as firms become more integrated, the likelihood of technology inclusion increases. In other words, the combination of vertical and horizontal integration results in greater inclusion of systemic technologies than just one type of integration (either vertical or horizontal). Both are better than no integration at all. Figure 1 visually demonstrates these results.

--- Figure 1 about here ---

The effect sizes, listed in Table 3, were calculated using the coefficients from the final, most complete model (Model 4 in Table 2). A few effects are especially noteworthy. The odds of inclusion of systemic innovations are 84% lower than for autonomous innovations. This effect is dramatic, especially in comparison to the smaller effect of technology costs, which decrease by a mere 8% for every dollar increase in cost above a standard technological alternative per square foot of building space. Cost becomes a more critical factor when the increase is greater than $11 per square foot, which is only the case for five of the twenty three technologies in this study. Even more dramatic, systemic innovations have 186% higher odds of inclusion if the firms are characterized by medium as compared to low integration, and 542% higher odds of inclusion if the firms are characterized by high as compared to low integration. We conducted several sensitivity analyses. For example, instead of testing the effects of low, medium, and high integration, we entered horizontal and vertical integration as separate variables, as well as their interaction. These and additional tests reinforce the robustness of our findings.

--- Table 3 about here ---

DISCUSSION

The standard product development model of cross-functional teams made up of members who are familiar with one another, engaged in frequent communication and guided by a strong leader does not fit the characteristics of complex one-off products and their production networks. Complex one-off products are developed by networks of specialized firms that come together temporarily for the purpose of producing a unit of the product. The breadth and depth of the required knowledge for the development of the products as well as insufficient profit margins typically renders lead firms unable to engage in extensive coordination. Instead, network firms coordinate themselves by relying on industry standards and shared knowledge that accumulates over time through training and experience. We show that this model of product development allows for innovation of complex one-off products as long as the innovation is confined to individual components without inducing system-wide changes. In other words, autonomous component innovations can be incorporated, but systemic component innovations are less likely. Our main contribution is that the knowledge and coordination challenges of incorporating systemic component innovations can be mitigated by horizontal and vertical firm integration. Our findings have important implications for the limits of industry standards and institutional knowledge, as well as firm integration as a strategic tool to increase innovation.

The limits of standards and institutional knowledge

The literature on standards (e.g., Garud et al. 2002; Jain 2012) acknowledges the ambivalent effect of standards on innovation. On one hand, standards enable innovation because users can develop or use different parts of a technological system in a distributed manner. On the other hand, standards constrain the evolution of technical systems to certain directions. Our study reinforces this observation, and also highlights the relationship between standards and industry-wide institutional knowledge. Standards not only clarify interfaces and product architectures. They are embedded in industry-wide shared knowledge about roles and professional jurisdictions, work processes, and communication channels. Together, standards and institutional knowledge allow for efficient and smooth functioning of temporary organizations of specialized firms. While in some temporary organizations, such as film crews and SWAT teams, professionals are able to shift roles, reorganize routines, and reorder their work (Bechky and Okhuysen 2011), complexity prohibits such actions in complex one-off products. Professionals are not only unlikely to know how to engage in such bricolage, but they are often unable to do so due to state licensing or work jurisdictional constraints (e.g., licensed architects and licensed structural engineers cannot legally do one another's work, and building trades' work boundary jurisdictions are rigid), technological constraints, fiscal constraints and risk aversion.

Firm integration as a strategic tool

By integrating, firms increase their capabilities and lower their transaction costs, and are thus better able to include systemic innovations into complex one-off products. Are firms then better off integrating then? Research across industries has found a general positive correlation between integration and organizational performance (e.g., Barki and Pinsonneault 2005; Barney 1991; Hoegl et al. 2004). Our findings, however, suggest that a more nuanced investigation is needed. We did not find a correlation between firm integration and innovation inclusion. It was only the interaction term between firm integration and systemic innovation that was significant. While firm integration facilitates the inclusion of systemic innovations, there is no evidence for any advantage to integrate when it comes to autonomous innovations. Moreover, not only is firm integration unhelpful when it comes to autonomous innovations, it can be even detrimental. Integrated firms bear a larger proportion of project costs and risk. Further, while integrated firms outperform non-integrated ones when systemic innovations are introduced, if they remain integrated and a different systemic innovation is introduced, they are likely to suffer performance consequences (Afuah 2001).

And perhaps, most importantly the building construction industry is subject to extreme demand fluctuation at the metropolitan or regional scale in which may of it members operate, Specialized firms are much better able to deal with high demand fluctuation than integrated multi-trade firms (Bourdon and Levitt 1980). This helps to explain the extreme fragmentation of the supply chain in this industry, in spite of the advantages that cross-trade firm integration provides in successfully adopting systemic innovations.

Shifting firm boundaries is not trivial and cannot be done in response to a single innovation. In attempting to optimize firm boundaries in order to increase capabilities and reduce costs associated with the inclusion of systemic innovations, it is important to consider the rate of change in an industry. For example, given the centrality of standards and institutional knowledge in developing unique, complex buildings, innovations in the construction industry tend to be autonomous and the overall rate of change is extremely slow. When a systemic component innovation, such as an intelligent building control system, enters the market place, it is likely to stay potent for some time as long as it reaches a critical mass. Therefore, firms may choose to integrate without worrying that their knowledge will quickly be made obsolete by a new systemic innovation.

For example, amidst contractors that are highly specialized to domains such as electrical or mechanical systems, Johnson Controls provides a counter example. In the building management domain, they began as a facilities operator for government buildings. Over time, they developed capabilities in controls and began integrating their own building management systems. In so doing, they evolved into a building energy management specialist that is completely vertically and horizontally integrated. They provide complete solutions for centrally managed energy systems in buildings to clients, all the way from requirement specifications, product sale, installation and integration to related building modules, calibration, and maintenance, and including financing and operation of building energy systems for the building owners as an energy supply contractor (ESCO) in many cases.

Qualitative background interviews that we conducted as part of our research program revealed that Johnson Controls' business model is common early on in the innovation life cycle when a systemic component innovation is introduced. Initially, when technology manufacturers introduce systemic component innovations, they vertically integrate and install them in buildings, or at the very least are present on site during the installation to guide the contractors. Once industry professionals become familiar with the technology, it is no longer a systemic innovation and the specialty contractors re-emerge. Johnson Controls began as an equipment manufacturer and over time transformed into a specialty contractor. Finally, once the technology becomes industry standard, the standard trades (e.g., plumbing, electrical, mechanical) and specialized firms that employ them can take over and install the technology in buildings. Examples of technologies that have come full cycle include daylight sensors and cooling towers. Technologies such as radiant heating and a smart building façades are still installed by specialty contractors. Newer technologies, such as the innovative and systemic RadiaGlass system by IntelliGlass, are offered as a complete solution and installed on site by the manufacturer (IntelliGlass 2011).

These examples, along with the findings of the paper, suggest a cyclical process of fragmentation and re-integration that may occur in industries like construction over time in responses to alternating pressures of systemic innovations and efficiency (see Figure 2). Prior to the emergence of standards, there is no clear industry-wide shared architectural knowledge. Firms need to be integrated to some degree in order to enable coordination and access to necessary knowledge. However, the emergence of a standard brings about the possibility of developing an industry-wide common language, which in turn enables production to move outside the boundaries of a single firm and into the realm of a network. At this stage, the introduction of an autonomous innovation leaves the shared institutional knowledge intact and therefore firm boundaries need not change. On the other hand, the introduction of a systemic innovation requires a change in institutional knowledge and consequently in the existing industry architectures. Shared templates are obsolete and the shared knowledge and standards can no longer serve as an embedded coordination mechanism among firms, rendering cooperation and new architectural knowledge acquisition without some integration or allying very difficult. Firms are thus better off integrating or allying. Once new standards that are based on the systemic innovation emerge, firms can once again fragment to focus on their core specialties, and to better address extreme fluctuations in demand, while outsourcing non-core aspects of design and production.

--- Figure 2 about here ---

Limitations and future directions

There are several directions for future work. First, we suggest that future research should attempt to disentangle the effects of specific types of integration on innovation inclusion. We examined two types of integration – horizontal integration via firm ownership and vertical integration via contractual arrangements. Data availability did not allow us to examine the effects of each form of integration separately. We found that being both horizontally and vertically integrated had better results for systemic innovations, but we cannot yet determine which type of integration is more effective. Second, future ethnographic studies could examine the effects of team integration on innovation inclusion to decipher the micro-foundations of the results. Third, our data was limited to one industry. There is reason to believe that systemic innovations would stagnate similarly in other industries in which unique, complex products are developed, but this warrants an empirical investigation. Fourth, the data in this paper are static. We investigated which innovative components were implemented into particular buildings. While the findings suggest a possible cyclical model of industry evolution in response to the emergence of standards and the introduction of systemic innovations, such a model needs to be substantiated empirically.

Integrated Project Delivery (IPD) is an emerging form of project delivery for complex buildings like hospitals that was adapted from alliance contracting in North Sea Oil projects. Hospital projects are technically complex, and rapidly evolving changes in the imaging, surgical, laboratory testing and other health care technologies they incorporate necessitate numerous changes of specifications by their owners during their five-ten-year delivery period. Under the integrated form of agreement (IFOA), used in IPD delivery, all of the key design and construction participants in the project are party to a single contract; they mutually waive liability against each other; and they are each reimbursed all of their actual direct project costs, plus a share of a project incentive pool to be determined by the client at the end of the project. Aside from the advantages of this form of contract in allowing for scope changes without renegotiation of multiple contracts, IPD projects also facilitate coordination across trades through: early involvement of contractors in design co-development; a shared, integrated digital building information model for the project to detect functional or spatial clashes more easily; and colocation of key participants in a project “Big Room,” in which each discipline’s designs are co-developed and overlaid in the shared digital project model. IPD is thus a form of “virtual horizontal and vertical integration” of the industry supply chain on a project-by-project basis, so it could plausibly offer many of the same benefits in facilitating systemic innovations as full, legal integration of firms was shown to do in this study. The number of IPD projects has now grown in the U.S. to the point that this hypothesis is now being tested.

Conclusion

Our core contribution is strong evidence that firm integration mitigates the coordination and knowledge problems induced by the introduction of systemic innovations into complex one-off products through the supply chains of mature industries like construction. The development of such products tends to take place in temporary organizations of specialized firms and relies on industry standards and institutionalized knowledge for its coordination. More horizontally and vertically integrated firms can transcend the "learning disability" of individual projects and constantly changing project team compositions by accumulating a broader knowledge base over time and applying it to enable more innovative projects.

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TABLES AND FIGURES

Figure 1

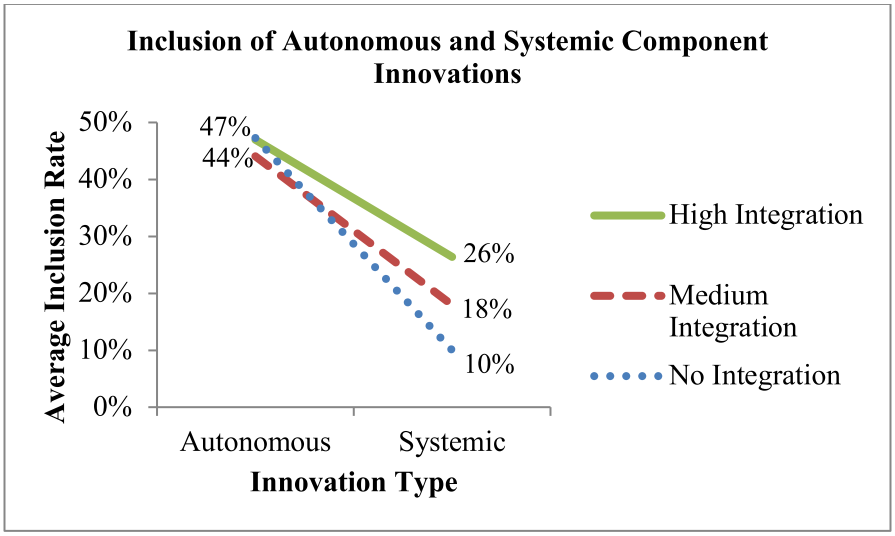

Figure 2

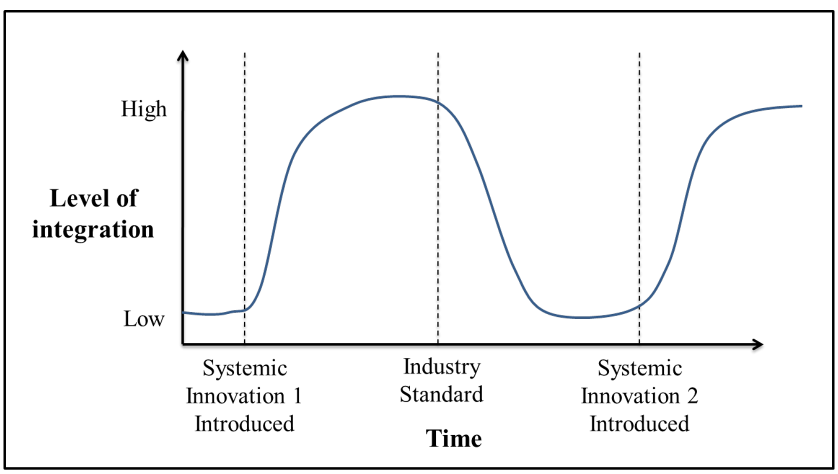

Table 1

Descriptive Statistics and Correlations											
Variable		Mean	S.D.	1	2	3	4	5	6	7	8
1	Inclusion	0.28	0.45								
2	Systemic innovation	0.52	0.50	-0.25***							
3	Firm Integration	2.04	0.68	0.06	-.002						
4	Cost	5.86	6.66	-0.22**	0.38***	0.01					
5	LEED score	39.12	8.96	0.07**	0	0.12**	0.01				
6	Profit organization	0.25	0.43	0.03	0	0.44***	.003	-0.12***			
7	Year	2002	1.80	0.03	0	0.24***	0.04*	0.23***	0.10***		
8	Firm size	1.66	0.74	-0.01	0	-0.25***	-.003	0.07**	0.02	-0.05*	
9	Firm core values	0.87	0.34	0.01	0	0.24***	.003	0.07**	0.09***	0.07***	0.02

* p<.1, ** p<.01, *** p<.001.

Table 2

GEE Logistic Analysis of the Likelihood of Technology Inclusion (N = 528 building-technology observations)

Variable	Model 1	Model 2	Model 3	Model 4
Intercept	-1.006****	-1.04****	-1.104****	-1.3****
	(.10)	(.10)	(.17)	(.20)
Systemic innovation		-1.02****	-1.02****	-1.82****
		(.17)	(.17)	(.32)
Firm integration (High)			.31	.52*
			(.28)	(.31)
Firm integration (Medium)			.03	.21
			(.27)	(.29)
Systemic innovation X Firm integration (High)				1.34***
				(.39)
Systemic innovation X Firm integration (Medium)				.84**
				(.40)
Controls				
Cost	-.11****	-.08****	-.08****	-.08****
	(.02)	(.02)	(.02)	(.02)
LEED score	.005	.005	.001	.001
	(.01)	(.01)	(.01)	(.01)
Profit organization	.55***	.58***	.51**	.50**
	(.20)	(.20)	(.23)	(.22)
Year	-.04	-.05	-.05	-.05
	(.06)	(.06)	(.05)	(.05)
Firm size	.17	.18	.17	.17
	(.11)	(.11)	(.11)	(.11)
Firm core values	-.36*	-.38*	-.44**	-.47**
	(.22)	(.23)	(.22)	(.22)
Quasi Likelihood under Independence Model Criterion (QIC)	620.47	599.29	599.92	596.71

* p<.1, ** p<.05, *** p<.01, **** p<.001; two-tailed tests. Robust standard errors are in parentheses.

Table 3

Effect Sizes

Variable	Coefficient	Effect Size
Systemic innovation	-1.82	-84%
Firm integration (High)	.52	68%
Firm integration (Medium)	.21	23%
Systemic innovationt X Firm integration (High)	1.34	542%
Systemic innovation X Firm integration (Medium)	.84	186%
Controls		
Cost	-.08	-8%
LEED score	.001	0%
Profit organization	.50	65%
Year	-.05	-5%
Firm size	.17	19%
Firm core values	-.47	-37%

Effect size = (EXP(β))-1*100%