Framework of construction innovation: A review of diffusion of sustainable innovation in the building sector

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ABSTRACT

The use of different theoretical frameworks and models of construction innovations is based on the particular characteristics of the construction work, including the types and modes of innovations, the “players” involved in the projects, and other influences. Recently, some new models have adopted new perspectives and approaches, such as socio-psychological perspectives, sociology of technology approaches, and actor-network theory. Some models were empirically tested with specific technological and non-technological innovations in architectural and engineering design firms. The goal of this study is to explore how sustainable innovations in the building sector can be understood through diffusion of innovation theories. To do so, previously proposed frameworks and models are critically reviewed; then, empirical studies are synthesized to find (in)consistencies in the literature. As a result, this study clarifies the commonalities and dissimilarities of the suggested models of construction innovation and discusses how different models supplement each other and can be combined. Attention to the process of adopting sustainable construction innovations reveals common challenges of sustainability, as well as leverage points where stakeholders can intervene in the building sector for sustainability. In the end, through the proposed theoretical framework, future research that can facilitate the adoption of sustainable innovation is suggested.

INTRODUCTION

The building industry is often viewed as lagging behind manufacturing sectors such as the automotive industry in terms of an inherent ability to innovate new ways of working and its seeming inability to adopt innovations from other areas (Harty, 2008). Many research have addressed this backwardness of the building industry (Winch, 1998; Gann & Salter, 2000; Nicolini, Holti & Smalley, 2001; Woudhaysen & Abley, 2004). Moreover, decentralized project-based organizations like the building sector rely on expert project managers and teams in organizational routines, and the experts often have a conservative influence on adopting innovation (Bresnen, Goussevksaia, & Swan, 2005). Other reasons for slow adoption of innovation can be found in the theories that are used in construction: applying production theories, which are limited due to different contexts, transformation models of production, which does not consider uncertainty or interdependence, and limited bottom-up innovation (Koskela & Vrijhoef, 2001).
Diffusion of innovation theories for understanding factors that influence adoption of innovations have been applied and modified in the context of the construction industry over the last two decades. The use of different theoretical frameworks and models of construction innovations is based on the particular characteristics of the construction work being analyzed, including the types and modes of innovations, the “players” involved in the projects, and other influences. Recently, some new models have adopted a variety of new perspectives and approaches, such as socio-psychological perspectives, sociology of technology approaches, and actor-network theory. Some models were empirically tested with specific technological and non-technological innovations in architectural and engineering design firms. The goal of this study is to review how construction innovations in the building sector can be understood through innovation theories.

METHOD

Inclusion criteria for studies in this review were: 1) book or research published in a peer-reviewed journal or conference papers; 2) published in English before July 25, 2013; 3) discussed diffusion of innovation and/or construction innovation theoretically or empirically. The review used Google scholar and three major databases: ABI; EI CompendexWeb; and ISI web of knowledge. Search keywords were “diffusion, innovation, diffusion of innovation, organization, construction, construction innovation, and building.” The researchers then sorted articles into two categories: diffusion of innovation in general and diffusion of innovation in the building sector. The goal for this review is to build a conceptual framework for diffusion of innovation in the building context. Meta-analysis was not appropriate because of the limited number of empirical studies on the topic and inconsistency of variables or design in terms of types of innovation, adopters and unit of analysis in the existing literature.

RESULT

The theory of diffusion of innovation has been developed and applied into many different disciplines such as sociology, communication, marketing and management, and public health and medical sociology. This section provides the brief overview of diffusion of innovation theory in general and then summarizes findings from the review of literature on diffusion of innovation in the building context.

Overview of Diffusion of Innovation

An innovation is defined as, “an idea, practice, or object that is perceived as new by an individual or other unit of adoption,” and diffusion is “the process in which an innovation is communicated through certain channels over time among the members of a social system” (Rogers, 2003). In Rogers’ diffusion of innovation model, the four elements of diffusion are: 1) innovation, 2) communication channels, 3) time, and 4) social system, and the innovation is perceived by its relative advantage, comparability, complexity, trial-ability, and observability. Innovations can be a product, a process (either a technological or administrative procedure), or a service (Rogers, 2003). Also, another way to categorize innovation is by degrees of
changes compared to the existing products, processes, or services (Anderson & Tushman, 1990).

Most of the innovations that have been discussed in diffusion studies are technological innovations. These studies reflect a belief that technology produces social changes in a system, often called technological determinism, whereas the process of diffusion explains a belief that social forces such as government regulation, social values, and human interaction shape technologies through a process of social construction, called social determinism (Rogers, 2003). The fields of organization and social movement focus on the structural and cultural logic of the diffusion process, for instance, why practices diffuse at different rates and through different pathways in different settings (Strang & Soule, 1998). The internal diffusion process works through information and influence flow within the adopting population depending upon actors’ relationships: cohesion works through strong ties, information collection through weak ties, structural equivalence and competition, prestige, and spatial proximity (Strang & Soule, 1998). Strong social ties drive frequent interaction among strongly related partners and an exchange of information on innovation, while weak ties deliver the new information of what others do (Strang & Soule, 1998).

Embedded social ties among actors affect organizational and economic outcomes and can be developed upon trust, fine-grained information, and joint problem solving arrangements, which is shown in the New York City apparel industry (Uzzi, 1997). The embedded ties facilitate “thick” information exchanges of tacit and proprietary know-how and create opportunities that are difficult to replicate via markets, contract, or vertical integration (Uzzi, 1997). Stronger ties create more effective communication channels among actors. On the other hand, arm’s-length ties are generated by the self-interest of actors, and actors tend to change their partners to take advantage of new entrants or avoid dependence (Uzzi, 1997).

Structurally equivalent actors who have similar ties mimic each other’s adoption behavior; prestigious and central actors, on the other hand, can influence adopters through social psychological and structural mechanisms (Strang & Soule, 1998). Also, spatially proximate actors who often have mutual awareness and interdependence can influence each other regarding adopting behavior (Strang & Soule, 1998). Such internal diffusion processes can be applied to social network theory meaning that actors are connected to a network that forms channels of communication and influence in inter-organizational studies (Greenhalgh, Robert, Macfarlane, Bate, & Kyriakidou, 2004). Also, organization-level factors such as stakeholder and takeover exposure influence the way in which different practices can vary during the process of adoption (Fiss, Kennedy & Davis, 2012).

Rogers (2003) described a six-step innovation process for an organization: 1) agenda setting, defining the need for and potential value of innovation; 2) matching the need and the technology; 3) decision-making on adoption; 4) redefining and restructuring the technology and the structure of the company; 5) elucidating the relation between the organization and the technology; and 6) routinizing the technology in the organization. The factors that influence decision-making on adoption, which is the third step of the innovation process, are knowledge, persuasion, decision, implementation, and confirmation. Learning, which is also an important factor in the diffusion process, provides communication channels for
information flow through either learning-by-doing or learning spillovers in the network of actors (Bol & Moers, 2010).

**Diffusion of Innovation in the Building Context**

Roger’s diffusion of innovation model has been applied to innovation in the building industry. Applying the diffusion of innovation model to the building sector requires careful consideration because of two assumptions in innovation theory in manufacturing: 1) Innovations are created by an internal research and development (R&D) organization (Nelson & Winter, 1982) and 2) Innovations can be utilized through large-scale mass production (Abernathy & Utterback, 1978). These assumptions are different from those in the building industry, which are limited investment on R&D and one-off project based work. The necessity of considering fundamental contextual differences in building projects and in other areas has been discussed to apply the innovation theory to the building industry (Sexton & Barret, 2003a, 2003b; Winch, 2003; Bresnen & Marshall, 2001; Green, Fernie & Weller, 2005). The purpose of this chapter is to review models of innovation diffusion adopted in the building context and clarify the process of adopting sustainable building innovations with the reviewed theoretical models.

There have been both theoretical and empirical approaches to understand the diffusion model and the process of the diffusion of innovation in the building sector. Slaughter (1998) suggested different types of construction innovation: incremental, modular, architectural, system, and radical innovation depending on the magnitude of change from current practice and the degree of interaction with other components or systems. Additionally, concerns in construction innovation in Slaughter’s (1998) model are: 1) timing of the commitment to use innovations; 2) implicit and explicit coordination among stakeholders; 3) types and sources of special resources; 4) the nature of supervision activities.

Many researchers take a process view of diffusion. Construction innovation is “a response to external needs, especially those of clients, by importing products and techniques from outside” (Gann, 2000). Some sources of process and product innovation in the construction industry are from within the construction industry, but forty percent of all innovations and fifty percent of product innovations originate in other industries such as chemical, metal, machinery, and electrical engineering (Pries & Janszen, 1995). Therefore, the process of adopting innovations is an interesting area to study. Like Rogers’ (2003), Shaffer’s (1985) five-step innovation development process focuses more on the technology transfer: problem identification, research and development, field demonstration, product/system authorization, and product/system application. Tatum (1987) described the process of innovation in construction firms specifically: recognize forces and opportunities for innovation, create climate for innovation, develop necessary capabilities, provide new construction technologies, experiment and refine the new technologies, and implement the new technologies. Also, organizational structure and culture are important in order to facilitate innovation by providing supportive policies, intra- and inter-organizational coordination, and staff (Tatum, 1987).

A model focusing on expert system technology explains that innovation can be either top-down or bottom-up depending on where initiation starts, either from
senior managers or from an individual who is not in a senior management group (de la Garza & Mitropoulos, 1991). Its process is as follows: 1) recognizing forces and opportunities for innovation; 2) identifying new technologies; 3) committing the initial resources; 4) evaluating the technology; 5) implementing the technology; and 6) confirming the value of innovation (de la Garza & Mitropoulos, 1991). Depending on the direction of the diffusion process, either top-down or bottom-up, several factors affect the process: the attitude of senior management toward innovation, the position of the individual identifying innovation, the capability of organization, the organizational environment, and the state of the development of innovation (de la Garza & Mitropoulos, 1991). Laborde and Sanvido (1994) proposed a model of innovation process for contractors: identification; evaluation of candidate technologies; implementation of selected technologies; and feedback as a result of innovation. They also compared variations in factors affecting the innovation process in small (local) and large (national) companies in terms of financial risk, R&D resources, internal communication speed, and management style. They found that small firms often have difficulties exposing themselves to financial risk and that these firms often lack resources for R&D, while large firms’ slow communication channels, and the hierarchical structure of the decision-making process makes the innovation process more difficult (Laborde & Sanvido, 1994).

Based on the type of innovation, whether it is project-specific or company-wide, the characteristics of the innovations are different in regard to the people involved, the time and resources available, the scope of technology search, and the payback period (Laborde & Sanvido, 1994). Key sources of innovative technology are suppliers (i.e., product manufacturer and software developers), subcontractors, contractor competition, construction research organizations and universities, employees, and formal in-house development efforts (Laborde & Sanvido, 1994).

A number of factors that influence the adoption of innovation can be categorized into five groups: market, product, management, building process, and sector characteristics (Pries & Janszen, 1995). Specifically identified are the variables that significantly influence management of innovation implementation: the expected purpose of the innovation for a better performance of the whole project and for a higher market reputation, general, technical, and managerial capabilities to implement innovation; and management-level and project-level efforts to implement innovation (Ling, 2003). This finding aligns with socio-psychological constructs such as leadership, team climate, and organizational culture, which are related to the underlying climate for innovation (Panuwatwanich, Stewart, & Mohamed, 2009). The team climate for innovation mediates the relationship between leadership and organizational culture for innovation and organizational culture works as a gateway for the diffusion of innovation shown in Figure 1 (Panuwatwanich et al., 2009). The leadership has an impact on creating both a team climate and an organizational culture that rewards innovation (Panuwatwanich et al., 2009; Sexton & Barrett, 2003a). As the organization culture for innovation improves, the level of innovation outcomes increases and eventually leads to higher business performance (Panuwatwanich et al., 2009).
If we think of a project environment in which many organizations work together for a single project, construction innovation can be thought of as an “inter-organizational landscape” in terms of leadership, team climate, and project culture, which is different from a single driving force for innovation in general innovation theory (Harty, 2008). A case of a Swiss contractor shows variables that significantly affect managing innovation, which are external variables (i.e., dependency on client and location, procurement form, client’s acceptance of innovation, and regulation) and internal variables (i.e., service offer, knowledge, cooperation, financial situations, and time required) (Hartmann, 2006).

Empirical studies on adoption of innovations such as CAD technology and ISO 9000 certification have found that the diffusion of CAD technology in architectural design practice and ISO 9000 in the precast concrete industry is driven by internal (i.e., copying behavior of others) rather than external (i.e., complying with client’s requirements, government regulations, demand conditions, and consulting firms’ suggestions) influence factors (Kale & Arditi, 2005, 2006, 2009).

DISCUSSION

Based on the literature, a conceptual framework for diffusion of innovation in the building context is proposed in Table 1. The conceptual framework includes four areas: external factors, internal factors, mechanisms, and outcomes. The framework focuses on the perspective of organizational study (Harty, 2008) and integrates types of innovation (Slaughter, 1998) and stakeholders in the building sector. The most recognized characteristics of construction are organizational complexity and the stakeholders’ fragmented relationships, which hinder the diffusion of sustainable building practices (Feige, Wallbaum, & Krank, 2011). However, the difficulties caused by these characteristics can be reduced depending on what type of relationships the stakeholders maintain with one another (Strang & Soul, 1998). The nature of these relationships can also affect leadership and project teams view for innovation, as how well information flows among the groups (Panuwatwanich et al., 2009; de la Garza & Mitropoulos, 1991; and Tatum, 1987). For instance, an embedded tie between an architect and a contractor may improve the project team climate for innovation and the flow of complex/tacit information, which is difficult to acquire from the market or contracts (Uzzi, 1997). Another example is that material suppliers who are structurally equivalent may share new industry information and
mimic the each other’s decisions regarding the adoption of innovation (Strang & Soul, 1998).

**Table 1. A conceptual framework for diffusion of construction innovation**

<table>
<thead>
<tr>
<th>External Factors</th>
<th>Internal Factors</th>
<th>Mechanisms</th>
<th>Outcomes</th>
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</thead>
<tbody>
<tr>
<td>Organizational complexity</td>
<td>Type of stakeholder</td>
<td>Leadership for innovation</td>
<td>Innovation diffusion outcome</td>
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<tr>
<td></td>
<td>Internal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>External</td>
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<td></td>
<td>Internal &amp; external</td>
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<tr>
<td>Fragmentation among stakeholders</td>
<td>Role of stakeholder</td>
<td>Project team climate for innovation</td>
<td>Project performance</td>
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<tr>
<td></td>
<td>Developer</td>
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<tr>
<td></td>
<td>Financial institution</td>
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<td></td>
<td>Architect</td>
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<td>Engineer</td>
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<td></td>
<td>Contractor</td>
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<td></td>
<td>Supplier</td>
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<tr>
<td></td>
<td>Owner/user, etc.</td>
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<tr>
<td>Type of innovation</td>
<td>Type of stakeholder relationship</td>
<td>Information flow</td>
<td></td>
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<tr>
<td>Incremental</td>
<td>Strong (embedded) tie</td>
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<tr>
<td>Modular</td>
<td>Arm’s-length tie</td>
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<tr>
<td>Architectural</td>
<td>Weak tie</td>
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<tr>
<td>System</td>
<td>Structural equivalence and competition</td>
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<td>Radical innovation</td>
<td>Prestige</td>
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<td></td>
<td>Spatial proximity</td>
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This conceptual framework can be applied to diffusion of sustainable construction innovation for future study. The following possible research questions can be either empirically tested or examined by qualitative approaches: 1) how are sustainable building rating systems (i.e., Leadership in Energy and Environmental Design (LEED)) related to type of innovation?; 2) which stakeholder is a central actor or an opinion leader in a project in terms of adopting innovation?; 3) is any type of stakeholder relationship among specific stakeholders preferred than others? (i.e., a strong tie between a developer and an architect is more influential than a strong tie between a contractor and a supplier or vice versa); 4) how is project team climate for innovation formed?; and 5) is project team climate for innovation related to innovation diffusion outcome?
CONCLUSION

The building industry faces the challenge of integrating many players and activities throughout a building’s life cycle to minimize the environmental impact of the building by adopting innovative processes and/or products. In order to achieve this goal, stakeholders’ engagement is necessary to achieve a cohesive structure by working together on (or for the benefit of) the project (du Plessis & Cole, 2011). This review paper provides a summary of the diffusion of innovation in the building sector specific and suggests a conceptual framework focusing on organizational factors in the building sector. Project-based organizations like those in the building sector may have difficulties developing or maintaining strong ties with other stakeholders for a short-term. However, developing strong ties among stakeholders can create leadership for innovation in the projects and improve the project team climate for innovation. Moreover, strong ties increase the flow of tacit information between stakeholders and allow them to take advantage of opportunities that are hard to obtain through market or contract. Therefore, developing strong ties with other stakeholders can benefit (all/most) stakeholders as well as the overall project in terms of innovation diffusion outcome and project performance.

REFERENCES


Shaffer, L. R. (1985). "Product/system development for military facilities; Briefing on high technology test bed concept." U.S. Army Construction Engineering Research Laboratory, Champaign, Ill.


