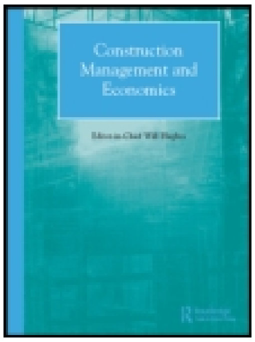

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John A. Gambatese & Matthew Hallowell

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Factors that influence the development and diffusion of technical innovations in the construction industry

JOHN A. GAMBATESE[1] and MATTHEW HALLOWELL[2]*

[1]*Department of Civil, Construction, and Environmental Engineering, Oregon State University, 202 Apperson Hall, Corvallis, 97331 USA*
[2]*Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, USA*

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Some technical innovations diffuse rapidly throughout the construction industry while others take a long time or are never integrated into everyday practice. Understanding the initiation, development, implementation and outcomes of successful technical innovations within the construction industry provides guidance for the improvement of the innovation process. To further this understanding, innovation generating organizations (IGOs) in the construction industry were surveyed and the data were statistically analysed. Two sources were used to identify newly developed products, technologies and management strategies: the Construction Innovation Forum's NOVA Award website and the Emerging Construction Technologies (ECT) website. A total of 233 innovative products were identified from the two websites. The results showed that there are many statistically significant motivating factors for investment in the initial development of successful technical innovation, barriers and enablers to efficient diffusion and innovation outcomes on construction projects. Additionally, successful development, implementation and diffusion of an innovative product required an average of 38 months, 4700 worker-hours and $836 000.

Keywords: Innovation, design, technology.

Introduction

There is a perception among some professionals that construction innovation is rare and that the industry is slow to change. This perception sometimes stems from comparisons of the construction industry to the electronics, medical and other industries in which the introduction and adoption of new technologies and products have been extensive over the past several decades. Despite this perception, innovation in construction does occur and has been documented by researchers (Slaughter, 1998). In fact, innovation in computer aided design, automation and simulation occurs to a great extent. Innovative products, means and methods, technologies, services and management strategies are essential to economic growth, sustained competitive advantage and the achievement of landmark projects (Schumpeter, 1934; Tushman *et al.*, 1997).

Innovations in the architecture, engineering and construction (A/E/C) industry may be initiated by any type of organization including, but not limited to: architects, engineers, contractors, subcontractors, academic research institutions and product development firms. From the perspective of a particular innovation, the firm that generates and implements a novel idea is known as the innovation generating organization (IGO) while the organizations that later adopt the innovation are considered to be the innovation adopting organizations (IAOs). IGOs are distinguished from IAOs for a particular innovation because they successfully initiate, develop and disseminate new products, technologies and services (Damanpour and Wischnevsky, 2006). It should be noted that the role of IGOs and IAOs depends on the innovation in question and that one organization may serve as the IGO for one innovation and as an IAO for others.

Though any firm can be an IGO for a particular innovation, there are specific companies that specialize in generating new products, processes or technologies and marketing these novel ideas to the industry. In this

*Author for correspondence. E-mail: matthew.hallowell@colorado.edu

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role, these firms tend to experience the entire innovation process and depend on unique technological knowledge and marketing capabilities to be successful (Fiol, 1996). Unfortunately, such organizations have not been included in previous studies of innovation in construction.

The present research aims to study the experiences of single-service IGOs (i.e. firms with the primary function of generating new products, processes and technologies for the construction industry) by evaluating the relative impacts of organizational characteristics, management strategies, market forces and resource investments on the development of technical innovations. Though other researchers have examined innovation within construction organizations (Taylor and Levitt, 2004) and project networks (Taylor and Levitt, 2005), no study has specifically focused on the experiences of successful IGOs in the construction industry or attempted to quantify the relative impacts of the factors that affect their innovation process. This study utilizes the experience of individuals within construction IGOs who have experienced the entire development and diffusion process of a technical innovation. The knowledge presented in this paper can be used by aspiring entrepreneurs and existing organizations in the A/E/C industry to increase the likelihood of success of development and diffusion of technical innovations.

Literature review

Innovative ideas may be generated by one individual or a group, from within or outside an organization, and take several months to develop or many years (Wolfe, 1994). Researchers have, however, identified practices commonly exhibited in the innovation process and have developed models that reflect the process. These models generally include all aspects of the innovation process including research and development (R&D), commercialization, diffusion, adoption by IAOs, implementation and consequences (Rogers, 1995). Bernstein *et al.* (1998), for example, identify four key steps of the innovation process in construction organizations: (1) generalization or conceptualization of an idea; (2) development and production of the new technology; (3) transfer of knowledge; and (4) subsequent application to solving problems. These steps are similar to those identified by Kangari and Miyatake (1997) who found that the innovation process incorporates three major activities in the progression from new idea to implementation: envisioning new work strategies, designing the process, and implementing change.

Abd El Halim and Haas (2004) propose that the process for construction innovation can be systematic and modelled the individual steps in the innovation process. The identification of, and need to solve, a problem is generally the impetus for innovation. The problem may be new or recurring, and requires a different approach to a solution. The process continues with traditional problem-solving activities (i.e. investigation of the problem and data gathering), brainstorming and development of a solution, testing of the solution, and implementation and realization of the solution (Rogers, 1995; Subramanian and Nilakanta, 1996; Schroeder *et al.*, 2000). Building on this previous innovation process research, Berkout *et al.* (2006) offer a ‘fourth generation’ innovation process model that describes the relationships that must exist among project players including innovators and adopting clients. This work confirms previous research and stresses the importance of innovation networks during implementation and diffusion.

Regardless of the process undertaken and the nature of the adopters, construction innovation will not occur in the absence of a motivator. Park *et al.* (2004) recognized that the conceptualization, development and implementation of a new product, method or system require that there be a motivation to drive the process. Without strong internal or external motivators employees will not generate new ideas and organizations will not evolve. While the most recognizable motivator is a specific problem that must be solved to complete a project or overcome an obstacle, effective diffusion requires motivators besides just solving a particular project problem (Macomber, 2002).

In addition to a motivator, an innovation must produce measureable improvements to project performance in order to achieve widespread diffusion. Toole (2001) claims that the success of an innovation depends on the ability of the innovators to show that the innovation will reduce cost, decrease task durations and enhance quality or safety performance. Construction innovation can also be driven by other industries. For example, inventions are often generated by equipment manufacturers that are then implemented by contractors and subcontractors. Such firms act as a catalyst by improving efficiency and allowing workers to perform more versatile tasks (Arditi *et al.*, 1997). Innovation is also motivated by competition among construction organizations.

There are many factors that are internal and external to an organization that enable and impede the innovation process. Some commonly identified factors include: contractor input during the design phase; overlap of the different project development phases; an organizational culture that supports innovation as a method of winning construction projects; and an organizational innovation ‘champion’ and entrepreneur, including a technical innovator, business innovator, product champion and chief executive (Tatum, 1986a, 1986b, 1991; Slaughter, 1993, 1998; Schein, 1999; Bossink, 2004). A study of innovation within homebuilding organizations added to this body of literature by identifying management strategies that differentiate successful firms (Koebel *et al.*, 2004). This study found that successful firms: (1) have motivated leaders; (2) have a technology advocate within the firm; (3) stress the importance of being creative and the first to use new products; (4) use technology transfer programmes; and (5) employ union labour forces. Less successful firms were found to have emphasized marketability and profit, associated the firm's development with the development of new land, and had a risk perspective that precluded investment in ideas that had not been tested and confirmed by other organizations. In a similar study, Blayse and Manley (2004) aimed to identify the key factors that influence construction innovation on projects, and identified the following as the six major influencing factors: (1) clients; (2) production structure; (3) innovation networks; (4) procurement systems; (5) regulations; and (6) organizational resources by focusing on the interface between innovation development and project implementation.

Recently, there have been several studies that evaluate factors that influence the adoption of innovations by IAOs. For example, Hartmann *et al.* (2006) developed and tested a conceptual framework for innovation adoption that suggests that IAOs must have a thorough understanding of the problem that the innovation is intended to solve; the innovation must be implemented early in the project development process; and information about competing solutions must be readily available. Similarly, Hardie *et al.* (2005) found that innovations are more successful in IAOs that are profitable and have invested time and resources in evaluating alternative strategies for problem solving. Finally, Manley *et al.* (2008) found that IAOs must work closely with IGOs, prioritize relationship building with these firms and honour proprietary information when initially implementing innovations.

Current literature provides an understanding of innovation within construction organizations (e.g. owners, architects, contractors and subcontractors) and on construction projects. Despite this wealth of knowledge, academic research has not produced compatible theories that can guide management practices for IGOs (Tidd, 2001). The study presented in this paper focuses on the experiences of a relatively large number of successful construction IGOs and attempts to identify the salient factors affecting the innovation process. The study was informed by, and attempts to validate and supplement, the relatively large body of literature available on organizational innovation.

Research method

The purpose of this research effort was to determine and evaluate the factors that influence the initiation, development, implementation and successful diffusion of technical innovations in the construction industry based on the experiences of successful construction IGOs. Specifically, the four research questions addressed by this study are as follows:

(1) What are the salient factors that affect the initiation, development, implementation and diffusion of the technical innovation process as experienced by successful construction IGOs?
(2) What are the relative impacts of these factors?
(3) What are the typical resource requirements for successful completion of the technical innovation process?
(4) What benefits are realized from successful completion of the technical innovation process?

According to Yin (2003) and Sillars and Hallowell (2009), such research questions are best explored using structured surveys of experts of the technical innovation process. The fact that most product development firms tend to keep proprietary product development knowledge confidential until the product has been completed and diffused precluded the use of case studies. Furthermore, simulation exercises and analysis of empirical data are inappropriate because there are no baseline data from which to sample, and previous literature has found process models for construction innovation to produce inconsistent results (Damanpour and Wischnevsky, 2006). Therefore, the selection of structured surveys of identified experts is appropriate for this inquiry.

The first research task was to identify construction IGOs that have successfully developed and diffused a technical innovation in the construction industry. Fortunately, there are two websites that publish information about award-winning innovations in the construction industry: (1) the Construction Innovation Forum's NOVA Award website (http://www.cif.org/); and (2) the Emerging Construction Technologies (ECT) website sponsored by Purdue University and the Construction Industry Institute (CII) (http://www.new-technologies.org/ECT/Index.html). The Construction Innovation Forum (CIF) is an international, non-profit organization formed in 1987 to recognize innovations in the construction industry that improve the quality, efficiency and cost-effectiveness of construction. Similarly, the ECT website was the product of a CII-funded research project that describes innovative materials, processes and systems that have been successfully implemented and diffused. These websites were considered to be credible and representative sources of construction innovations because they are published by leading construction research institutes and forums. Furthermore, after a thorough literature review, the writers believe that these are the best collections of successful innovations from the past decade. The data from these websites were used to obtain contact information for the IGOs and to create a demographic profile of the innovations represented.

All of the 233 products, technologies and management strategies listed on the websites were recorded (155 from the NOVA website, 77 from the ECT website, and one from an outside reference), for which e-mail addresses of 189 were obtained. Forty-four of the innovations included on the websites did not have associated contact information and, consequently, could not be included. To conduct the survey, a questionnaire was developed and distributed to the 189 developers via e-mail. A few limitations of this sampling strategy should be noted. First, the external validity (i.e. generalizeability) of the results is limited because only successful IGOs whose innovations were highlighted on the NOVA and ECT websites were included in the analysis. This sampling strategy reflects the difficulty associated with identifying successful innovations and obtaining contact information for the IGOs responsible. Despite this limitation, the writers believe that there is much to be learned from the experiences of these IGOs, even if these experiences aren't shared by all IGOs.

The questionnaire solicited information regarding: the demographics of the respondent and the respondent's company; the nature of and impacting issues experienced during the conception, research, development and implementation of the technical innovation; the motivators, barriers and enablers experienced during development and diffusion; and the organization's climate and structure. The structured survey questions were created based upon the findings from the literature review as described in the previous section of this paper. In addition to the structured survey questions, respondents were also asked to describe the product, technology or management strategy and its extent of use.

One objective of the survey was to identify the barriers and enablers experienced by the IGOs during the development and initial diffusion of technical innovations. Enablers were defined as those processes, resources or systems internal and external to a firm that facilitate the innovation process while barriers were defined as the factors that limit idea generation and/or impede the innovation process. The survey respondents were asked to indicate the extent to which enablers and barriers identified in the literature review affected the implementation of their products on projects by rating the impact of potential as: none, small, moderate, significant or extreme. The survey also asked respondents to rate the relative impact of identified motivators and allowed respondents to add and rate additional factors that were not identified from literature. The structure of the survey was based upon relevant literature. The closed-ended questions asked respondents to 'rate the impact that factor X had on the diffusion of your technical innovation'.

A total of 34 responses were received (18.0% response rate). This response rate is reasonable given the fact that organizational leadership was contacted and asked to provide funding, research, development and other sensitive information. The respondents who completed the questionnaire had an average of 23 years of professional experience in the construction industry and held a variety of positions within the development firm including: president, CEO, CIO, project manager, technical director, marketing director and scientific director.

Research findings and discussion

The units of analysis were single-service IGOs. Unlike previous studies, this research does not focus on project-based innovation. Rather, the aim was to evaluate the factors that influence the initiation, development, implementation and diffusion of innovations generated by firms whose primary function is to innovate. The survey responses were recorded and analysed to identify common themes in the data. The technical innovations were grouped into several categories: information technologies, computer-based electronic devices; end products (both design and construction); construction means and methods; and construction equipment. The type and number of technologies in each category are presented in Table 1. Most of the respondents (73%) indicated that their firm independently generated the products without substantial external influence. Products were adopted from another industry by 15%

Table 1 Types of innovations

Category	Innovative product
Information technologies	Project information management system (1) Lessons learned systems (2)
Computer-based electronic devices	Estimating and bidding software (1) Project control system (1) Leak noise correlator (1)
End products (design and construction)	Material products (5) Mechanical products (7) Electrical products (2)
Construction means and methods	Concrete formwork/placement (5) Task management (2) Welding (1)
Construction equipment	Heavy/civil equipment components (5) Concrete materials washout (1)

of the respondent firms, and the remaining (12%) adopted the technologies from another source or firm within the construction industry.

One can see by studying Table 1 that the majority of the innovations studied were related to improvements in operations (e.g. tools, materials and equipment) and very few were process innovations that improve organizational performance at a strategic level. The implication is that strategic innovations that affect processes occur to a lesser extent, are more difficult to recognize or are less tangible.

To confirm the respondents' knowledge of the innovative products identified, the questionnaire asked about the extent of their involvement with development. Sixty-two per cent of the respondents stated that they were integrally involved in conception of the product idea, 59% were integrally involved in R&D and 76% were integrally involved in implementation. To get a sense of the magnitude of effort expended by the entire firm, the questionnaire also asked about the level of resources invested in R&D of the product. On average, the development of the technical innovations required 4677 worker-hours in R&D, 38.4 months and $836 000.

The IGOs utilized a variety of processes, resources and systems during development and initial dissemination efforts. Almost all of the firms (91%) have employees dedicated to developing new products. Formal methods for capturing and disseminating lessons learned are present in 82% of the firms, 70% have an innovation budget, 58% have a formal innovation plan and 56% hold formal innovation meetings on a regular basis. It is clear that the product manufacturers incorporate practices that enhance innovation to a great extent into the organizational structure and climate of their organization.

Factors affecting the generation and development of technical innovations

Survey respondents were asked to indicate the extent to which certain barriers, enablers and motivators affected the implementation of their products on projects by rating the impact of potential factors as: none, small, moderate, significant or extreme. While some of the results are consistent with existing literature, other results are contradictory indicating that the experiences of successful construction IGOs may be different from traditional models. The survey results confirm the findings of previous studies but conflict with others. For example, effective upper management (e.g. participation in research and development activities, allocation of resources and demonstrated commitment) was rated as a significant or extreme enabler by 82% of the respondents. Other enablers that were most commonly rated as significant or higher were: owner/client support (80%), organization culture (79%), an innovation 'champion' within the firm (76%), communication among the project team (71%) and communication within the firm (65%).

Despite the fact that project delivery method and overlap of design and construction were identified by the literature as essential to the innovation development process (Ahmad, 1991; Slaughter, 1993, 1998; Christensen, 1997), developers and manufacturers of products generally feel that their products can be implemented and diffused regardless of the project contracting strategy and phasing. In fact, project delivery method and the overlap of design and construction were not considered to be as strong factors, receiving significant or higher ratings by only 27% and 25% of the respondents, respectively. It should be noted that it is very likely that the influence of project delivery method is highly dependent on the innovation under investigation.

In addition to validating current literature, this study aimed to supplement the relatively small body of knowledge regarding the relative extent to which the various factors impact on the generation, initial implementation and diffusion of IGOs' technical innovations. To date, most literature focuses on impact factors within IAOs and the factors that influence project-related innovation required to address project-specific engineering, design and construction challenges. The barriers to the generation of new ideas and initial implementation include: lack of technical capabilities (18%), industry regulations and codes (17%), not applicable to all projects (17%), long payback period (15%) and project delivery method (15%). Barriers to diffusion included: clients' fear of change (53%), lack of recognition of the value of the innovation (35%) and lack of communication (24%) between the IGO and construction clients (i.e. end users of the construction innovation). It is interesting to note that, similar to the responses regarding enablers described above, project delivery method was not identified as a significant barrier to the innovation development process.

The survey respondents were also asked to rate the extent to which various motivators affected the innovation process using the same Likert scale. Table 2 shows the percentage of respondents who rated the reasons as significant or higher in the motivation for the innovations. Cost savings, competitive advantage, improved quality and increased productivity were the highest rated motivators. It should be noted that competitive advantage is often judged based on cost, quality and productivity performance relative to competitors. Hence, competitive advantage can be interpreted as also meaning cost savings, higher quality and increased

Table 2 Comparison of innovation benefits and motivators

Factor	% of respondents who identified the factor as a significant or higher motivator	% of respondents who identified the factor as a significant or higher benefit
Cost	89	66
Productivity	80	71
Quality	83	80
Competitive advantage	85	90
Market share	59	48
Safety	65	63
Marketing	51	48
New market	52	57

productivity, and therefore is a duplicate response. These findings confirm the findings of Toole (2001) and depart from that previous study by producing relative impact ratings.

Benefits and outcomes of technical innovation

Participants in the study were asked to identify the benefits and outcomes of innovation. While the respondents recognized that there are significant barriers to innovation, they also acknowledged that innovation does occur and has significant benefits. The survey asked the respondents to identify and rate the outcomes of their innovation. Table 2 shows the responses in comparison to the motivators for implementing the innovations. Decreased cost, competitive advantage, higher quality and increased productivity were the most highly rated benefits of the innovations.

Implementation and diffusion of innovative products

One indicator of the success of an innovation is the extent to which it has diffused throughout the industry. Greater diffusion indicates that the new technology provides value that the user recognizes as adding to the financial success of the firm, and that positive change has occurred. Respondents were asked to rate the extent of diffusion of their product into the A/E/C industry using the same Likert scale. Half of the respondents indicated that some diffusion has occurred (mean = 3.1, median = 3).

These results were compared to literature that focuses on IGOs in industries other than construction. These findings support past research that indicates that attributes of the innovation itself have a major influence on its generation and adoption (Meyer and Goes, 1988; Gopalakrishnan *et al.*, 1999; Wilson *et al.*, 1999; Gatignon *et al.*, 2002), and that organizations which have experimental cultures, entrepreneurial climate, decentralized structure, flexible work processes and strong technical competencies tend to produce more radical and successful innovations (McGrath and MacMillan, 2000; Tushman and Smith, 2002). These findings do not support Eisenhardt and Tabrizi's (1995) and Tushman and Smith's (2002) assertions that all innovations require an IGO to have an efficiency culture, a centralized structure, engineered work processes, and formalized roles and coordinating mechanisms. Unlike the present study, this previous work focused on strategic innovations that affect organizational processes. The implications of the results presented here, however, indicate that operational innovations may be successfully diffused even if the developing organization doesn't have some of the organizational characteristics previously thought to be required.

Analysis

The results from the survey were used to statistically evaluate the relationship between different impacting factors and innovation outcomes. Guidance from Ramsey and Schafer (2002) was used for all statistical analyses. A factor analysis was performed to evaluate the presence and strength of the relationship between leading indicators and innovation diffusion. For each factor a coefficient of determination value (R^2) and the beta coefficient (β) were computed. The R^2 value provides an indication of the accuracy of the model, i.e. how well the independent variables (leading indicators) predict the dataset (innovation diffusion). R^2 values closer to 1.0 indicate a better prediction (goodness of fit). The beta coefficient is computed on variables that have been standardized so that their variances are 1.0. This is done to identify which of the independent variables have a greater impact on the dependent variables when multiple variables are considered that have different units of measure. In addition, p-values were also calculated for each relationship to provide an indication of the probability that the observed relationship is due solely to chance. Only factors with a p-value of less than 0.10 are reported and discussed in this paper as it is highly unlikely that these relationships would have occurred randomly. It was also established through visual inspection and an analysis of residuals that the normality, equal variance and independence assumptions required for regression were satisfied. Furthermore, tests of multicollinearity revealed no relationships among explanatory variables. Finally, there were no significant outlying responses, skewness or indications that the data followed alternative distributions.

As will be discussed, a factor analysis was performed on the dataset to quantify the relative impact of any statistically significant factors that influenced the diffusion of the technical innovations. This was the ideal test given the objective of the study. Since the results were significant to a p-value of 0.10 or less, alternative analyses such as Fisher's Exact Test and structural equation modelling were deemed unnecessary.

Marketing of the innovation

The extent to which the product manufacturer interacts with the industry with respect to the specific innovation can impact on the success with which its innovation diffuses. Those respondents who indicated a greater extent of diffusion of their innovation also indicated that more extensive marketing of their products was undertaken ($\beta = 0.55$; $R^2 = 0.85$). For example, for those respondents who indicated that 'significant diffusion' had occurred ($n = 11$), the mean degree of influence of 'extent of marketing' on the diffusion was 3.7 (1 = low, 5 = extensive). This degree of influence is greater than the mean degree of influence given by those respondents who indicated a lower level of diffusion.

Barriers to implementation of the innovation

As stated previously, the respondents indicated that fear of change, innovation not being recognized by clients and lack of communication are the most significant barriers experienced by the IGOs. However, the relationship between experiencing these barriers and successful generation and diffusion was not found to be strong. The only barrier with a significantly high correlation of determination to diffusion was risk of failure ($\beta = -0.15$; $R^2 = 0.98$). Those respondents who indicated a greater level of diffusion also indicated that risk of failure of the innovative product was less of a concern (negative correlation). The implication is that IGOs that are involved in the diffusion of operational innovations are willing to take calculated risks.

Enablers of implementation of the innovation

Similar to barriers, no association with diffusion was found with the highest rated enablers (effective upper management, owner/client support, organization culture and presence of an innovation champion). Two enablers, the level of communication within the firm ($\beta = 0.33$; $R^2 = 0.88$) and the amount of funds available for research and development ($\beta = 0.24$; $R^2 = 0.89$), were found to have positive association with the extent to which the innovation has diffused throughout the industry. Those respondents who indicated greater diffusion also indicated a higher level of communication and a greater amount of available funds dedicated to innovation efforts.

Outcomes of implementation of the innovation

The respondents indicated numerous beneficial outcomes resulting from implementation of the innovative products. Three of the outcomes were found to positively correlate with diffusion of the products: improved quality ($\beta = 0.45$; $R^2 = 0.99$), appearance of new markets ($\beta = 0.80$; $R^2 = 0.98$) and increased market share ($\beta = 0.55$; $R^2 = 0.94$).

Innovation structure and climate

When the organizational culture is open, accepting of new ideas and willing to change, the potential for innovation is increased. Closed, conservative and highly standardized organizations exhibit a culture that is not conducive to innovation. These relationships are strongly supported by McGrath and MacMillan (2000) and Tushman and Smith (2002). Unfortunately, organizational culture is difficult to measure. Assessing organizational culture requires in-depth study of both explicit features and tacit knowledge within an organization, and is beyond the scope of this study. However, climate, a component of an organization's culture, was investigated. Climate is characterized by the employment surroundings, both physical and organizational, within which the employee acts. Examples of factors that impact on organizational climate with respect to innovation include upper management's emphasis on innovation and whether formal recognition is given to those employees who innovate. Three factors related to organizational climate were found to positively correlate with diffusion of the products: the extent of communication ($\beta = 0.33$; $R^2 = 0.92$), encouragement from management to 'try something new' ($\beta = 0.55$; $R^2 = 0.94$), and conducting formal innovation meetings ($\beta = 0.95$; $R^2 = 0.96$).

Formally including innovation in an organization's strategic plan and administration emphasizes the importance of innovation to the employees which can motivate workers in the innovation process (Steel, 2001). An organization's structure should, however, not be overly restrictive, complicated or multi-layered, or stifle opportunities for developing and implementing new ideas. Example indicators of the organizational structure related to innovation are: presence of an innovation champion, lessons learned/knowledge management, upper management support, and research and development. However, no association between organizational structure factors and extent of diffusion was found.

Study limitations and bias

As with many studies of the construction industry, the selected research methods and data used in the studies can inhibit the generalization of the findings beyond the study sample. One limitation impacting on the study is the data collection process. The surveys were not distributed to a random sample of the construction industry. Since the population was not randomly sampled, statistical inferences could not be made to the study population which, in this case, consists of all of the firms that produce products for the construction industry. Inferences can be made only to the dataset and generalization to the population is speculative. Furthermore, this study relies on a fundamental assumption that the products, technologies and management strategies highlighted by the ECT and NOVA websites represent innovations in the construction industry. Regardless of the validity of this assumption, these websites were used to identify new strategies that could be analysed to determine the extent to which they are innovative and the factors that affect their development, implementation and diffusion.

A second limitation is associated with the study inferences. The respondent input to the survey is observational data and cannot be used to make cause and effect statements. The quality of the data is subject to the perspectives and biases of the research participants. When rating their own products or their own firm, participants may give ratings that are biased because of personal or other influences. The ratings given may be high or low, and open-ended responses may be severe, supportive or off-base, because of the biases of the participants.

Another limitation is the small sample size. The sample size was small because of the difficulties encountered in soliciting information from random firms with which there is no pre-established relationship. The researchers relied on the goodwill of the participants to provide product information and take the time to complete the survey. A larger sample size would provide greater confidence in the results; however, obtaining contact information for a large number of individuals who were intimately involved in the innovation development process may be difficult.

The characteristics of the survey respondents are also a recognized limitation of the study. The respondents fill different roles in their firms and are at different levels of employment. The different hierarchal and functional positions affect their perspectives of the products and the factors impacting on diffusion of the products. This limitation also makes generalizing the results outside the study sample speculative.

Finally, though some questions in the survey asked respondents to rate factors related to organizational structure and these factors were correlated against innovation diffusion in a factor analysis, it should be noted that the organizational structure may have changed between the time that the innovation was initially diffused and the time that the survey was taken. According to the data, there was an average lag of two years, which may have a negative influence on the results.

Conclusions and recommendations

In its simplest form, innovation is positive change that results from the implementation of new ideas. This change can be in the form of new products, new processes or systems that are new to a firm and which is non-trivial. A perception exists that innovation in the construction industry is lacking or occurs at a very slow pace. However, all companies must innovate at some level in order to stay competitive in an open market in any industry. Therefore, innovation in the construction industry may take place at a low rate compared to other industries due to the structure and characteristics of the industry and projects, but it does, and must, occur in a competitive market.

This inquiry provided an opportunity to understand innovation from the viewpoint of single-service IGOs, the organizations responsible for creating and developing innovative products, technologies and services. The manufacturers of products that have been integrated into the design and construction process have experienced the innovation process and successfully overcome barriers to innovation. The experiences of these firms can provide guidance to the construction industry on how to facilitate future innovation, and to other product manufacturers on what to expect and plan for as they embark on the innovation process. The results of this study, which primarily apply to IGOs, indicate that:

- Factors commonly cited as innovation enablers are: support from upper management, owner/client support, organization culture, presence of an innovation champion, communication.

- Fear of change, lack of recognition from clients and a lack of communication are commonly cited barriers to innovation.
- Cost savings, competitive advantage, improved quality and increased productivity are commonly cited motivators for innovation. The outcomes of innovation are primarily: decreased cost, competitive advantage, higher quality and increased productivity.
- Diffusion of innovative products, and thus innovation across the industry, is greater as: marketing efforts increase, and the amount of training required to understand and implement the technology decreases.
- Diffusion was greater for those product manufacturers that identified entrance into a new market, improved quality of work and enhanced marketing as motivators to a greater extent.
- There is a greater level of diffusion of innovative products as the perceived risk of failure decreases.
- Diffusion of innovative products was greater for those manufacturers which indicated the following as potential outcomes of use of the innovation: increased market share, improved quality, appearance of new markets and assistance with marketing.
- Increased diffusion is tied to increases in the extent of communication, encouragement from management to 'try something new', and conducting formal innovation meetings.

While innovation within such a large industry as the construction industry might be considered by some as overwhelming and a daunting task, it should be recognized that innovation can occur at all different levels. Change can be big or small. However, it is much easier to create the change if it is small, and it is more reliable as incremental innovation tends to be more prevalent than radical innovation (Damanpour and Wischnevsky, 2006). The change is significant if it is positive, regardless of its magnitude. Whatever its size, innovation within the construction industry continues to attract attention and motivate those involved to continually search for how to do it better.

As with most research studies of complex and far-reaching topics, conducting the studies leads to additional questions and the identification of further needed research. First and foremost, the writers suggest a qualitative analysis of this topic, using interviews or case studies, to validate the results and to obtain qualitative data. Further research is suggested on the following topics:

- *Identification and dissemination of new technologies, systems and processes that have the potential to become innovations within the construction industry.*
- New products and processes are being developed within and outside the construction industry that have the potential for widespread use and impact within the industry. A barrier to their acceptance and use is a lack of knowledge of the innovations. A research effort is needed to identify prospective innovations that have a high potential for becoming innovations for the construction industry.
- *Further research and development of new technologies, systems and processes that have been identified as promising innovations for the construction industry.*
- Following the identification of potential innovations, research should be conducted to develop the innovations for widespread use in the construction industry. This effort could begin by rating the listed innovations for their potential impact and benefit.
- *Identification of the characteristics of the innovation adopters in the construction industry.* Daft (1982) showed that the experience of organizations who innovate primarily through adoption (IAOs) is very different from that of IGOs. Research is needed to identify the characteristics of each group with respect to the construction industry. The early adopters in the construction industry, for example, may consist of medium- to large-sized design firms in metropolitan areas who employ workers with both design and construction experience. This research would benefit the entire industry by helping to increase the rate of industry acceptance and implementation.

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