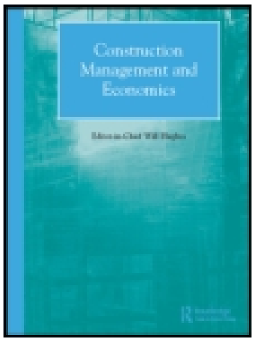

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Enabling and measuring innovation in the construction industry

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

[1]*School of Civil and Construction Engineering, Oregon State University, Corvallis, USA*
[2]*University of Colorado, Civil, Environmental, and Architectural Engineering, 428 UCB, 1111 Engineering Drive, Boulder, 80303, USA*

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Innovation is vital to successful, long-term company performance in the construction industry. Understanding the innovation process, how innovation can be enhanced and how it can be measured are key steps to managing and enhancing innovation. The factors that affect innovation on a project were identified, as well as how these factors can be used to measure the level of innovation on a project, and the practices and processes that encourage and facilitate innovative changes. Case studies of construction projects in the United States revealed three necessary components of innovation: idea generation, opportunity and diffusion. A variety of practices are used to optimize each component including support and commitment from the owner/client and firm upper management, workforce and project team integration and diversity. Applying the practices identified in the research leads to enhanced innovation through better communication among project team members, integration of the design and construction disciplines, more efficient designs, development of unique ways of completing work and sharing of the lessons learned. The end result of innovation will be projects that successfully meet and exceed cost, quality, schedule and safety goals.

Keywords: Integrated team, innovation, organizational culture, organizational behaviour, project management.

Introduction

There is continued interest in determining how to enhance innovation in the construction industry. Innovation, the implementation of a process, system or product that is new to an organization, can lead to decreases in cost and schedule, and improvements in quality and safety along with an increase in market share, a competitive advantage and increased technical feasibility of projects (Madewell, 1986; Slaughter, 1998). In fact, researchers and practitioners have found that innovation is a requirement in order for organizations to prosper or survive in a dynamic environment (Howell and Higgins, 1990; Damanpour and Schneider, 2006). These studies provide evidence that innovation is essential for continued organizational success and the advancement of the industry, and thus is an important topic for research.

Slaughter (1998) defines innovation as the 'actual use of a non-trivial change and improvement in a process, product, or system that is novel to the institution developing the change' (p. 1). Further, the term *innovation* is distinguished from *invention*, in that invention constitutes a detailed design or physical manifestation that is novel when compared to the existing practices—whether the invention is actually employed in practice or not. Innovation, however, includes both invention and the application of the invention. Additionally, innovation within an organization may be the application of a technology or method that is currently within the realm of existing practices but is just new to the organization adopting it.

Studies of innovation within an organization have focused on a variety of impacting factors. Factors examined include: demographics and experience of managers (Hausman, 2005; Lee *et al.*, 2005), organizational

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

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attributes (Wolfe, 1994), environmental antecedents (Damanpour and Schneider, 2006; Thornhill, 2006) and sociopolitical factors (McQuater *et al.*, 1998; Ortt, 1998; Kotler, 2002). Other researchers have investigated patterns of co-innovation (extending the scale and scope of external partnerships and alliances to access and exploit new technologies, knowledge and markets) (e.g. Rothwell and Dodgson, 1991; Tidd, 2001; Bossink, 2004) and the impacts of environmental and contextual factors such as policy, economics and industry sector (McQuater *et al.*, 1998; Ortt, 1998; Kotler, 2002). Despite this extensive literature, there has yet to be an attempt to study the project-specific factors that affect contextual innovation and co-innovation on construction projects. In other words, the impacts of construction-specific contextual and inter-organizational factors on the generation, implementation and diffusion of new products, processes, technologies and services, have not yet been addressed through rigorous research. The project characteristics that produce the context in which companies make their decisions concerning innovation management play an essential role in the successful development and implementation of innovations in project-based industries such as the construction industry (McQuater *et al.*, 1998).

The body of knowledge of contextual innovation is relatively small and limited in its practical application. For example, previous studies give conflicting evidence regarding the impact of multi-functional project teams. In a study of how contractors can successfully introduce new technologies, Laborde and Sanvido (1994) found that it is important to have a project team that consists of the necessary technical capabilities and involves the owner/client. Likewise, Cooper and Kleinschmidt (1994) studied 103 new product projects in the chemical industry and identified the use of a cross-functional, dedicated, accountable team as a significant factor in delivering a project. Alternatively, Atuahene-Gima (1996) studied service providers in comparison to product development firms and found that it is often more advantageous for service providers to engage in individual, long-term customer relationships. Studies have focused on individual technologies at the project level, yet the interrelationship among the industry providers at the industry level and project level is also viewed as both an inhibitor and enhancer of an innovative environment. One example is Damanpour and Wischnevsky's (2006) investigation of product and process innovations at the firm level over time. The researchers found that product innovations are adopted at a greater rate than process innovations, and a 'product-process' pattern of adoption is more likely than a 'process-product' pattern. Tatum (1986a, 1986b) found organizational characteristics that favour successful innovation are: attention to user needs and marketing; product uniqueness, marketing knowledge, technical and production synergy; and in-depth understanding of customers and market.

Addressing the deficiency in construction innovation literature requires an investigation of the indicators of innovation and the magnitude of their impact within the context of specific projects. This can be achieved through examination of past and current projects that vary in their characteristics (i.e. methods of project delivery, contracting strategies, funding schemes, climate and shared values within and among participating organizations). The present study was designed to: validate existing literature that models the factors that enable and impede innovation within and among organizations; determine additional project-specific factors that enable and impede construction innovation; and identify leading and lagging indicators that can be used to measure innovation potential and innovation success, respectively.

Literature review

Studies of the individual, organizational and environmental antecedents of innovation abound in social science literature. Themes within this body of literature include the impacts of project managers on the innovation process (Damanpour and Schneider, 2006), impacts of elements in the external project environment (Barney, 1991), influence of organizational characteristics (Kreiner and Schultz, 1993; George and Farris, 1999), innovation process modelling (Bernstein *et al.*, 1998), factors that contribute to co-innovation (Rothwell and Dodgson, 1991) and contextual innovation (Ortt, 1998). The following is a brief discussion of the literature related to construction innovation that illustrates the point of departure of this inquiry.

One of the most impactful factors on innovation within organizations is the specific characteristics of project managers and supervisors. Research on this theme is already extensive. For example, researchers have found that the innovative capacity of an organization is highly influenced by: senior managers' tenure in their position (Hambrick and Mason, 1984; Huber *et al.*, 1993), industry experience (Damanpour and Schneider, 2006), age (Huber *et al.*, 1993; Damanpour and Schneider, 2006), gender (Sonfield *et al.*, 2001; Stelter, 2002), education (Hausman, 2005; Lee *et al.*, 2005), willingness and ability to manage conflicts (Hausman, 2005) and willingness to share control (Scott and Bruce, 1994; Timmons and Spinelli, 2004). In addition to the specific characteristics of key individuals, there are organizational and environmental antecedents for innovation. For example, business resources (Barney, 1991), business structure (Burns and Stalker,

1961) and organizational culture (Chandler *et al.*, 2000) have all been found to impact on innovation. Additionally, the political, social, technical and environmental dynamics may contribute to turbulence and uncertainty which can impede innovation (Lowndes and Skelcher, 1998; Thornhill, 2006).

Success in the construction industry requires effective inter-organizational management. That is, construction projects often require collaboration among and management of diverse firms in order to achieve a common goal. Research on inter-organizational factors affecting innovation is extensive as well. For example, regardless of industry type, Rothwell and Dodgson (1991) found the compatibility of organizations is essential to successful co-innovation and value engineering. To achieve innovation success, firms must have common or complementary goals and share resources, knowledge, technical capacity and competencies (Grandori and Soda, 1995; Osborn and Hagedoorn, 1997; Oliver and Ebers, 1998). In an effort to model inter-organizational innovation Kreiner and Schultz (1993) identify three critical stages that can cross organizational boundaries: (1) discovery; (2) exploration of collaborative opportunities; and (3) crystallization of collaborative relations.

Examples of project-specific factors and inter-organizational management strategies that enable construction innovation to occur, or accelerate, are limited but can be found in the literature. In multiple studies of construction projects and firms, Tatum (1986a, 1986b and 1991) identified project-level factors as including: contractor input during the design phase; overlap of the different project development phases; an innovation 'champion' and entrepreneur, including a technical innovator, business innovator, product champion and chief executive. Slaughter's (1993, 1998) studies of the relationship between builders and 34 technical innovations, and of different categories of innovation (incremental, modular, architectural, system and radical innovations), confirmed the project-specific factors as key to innovation success. A recent study took a different track and looked at assisting organizations, or 'innovation brokers' as factors affecting innovation (Winch and Courtney, 2007). The study revealed that innovation brokers play an important role in some innovation processes by various means including facilitating diffusion, reducing risks for adopters, acting as a liaison between the sources of innovation and the adopters. Broker organizations may be not-for-profit, and can act at the level of the innovation, project, organization and industry.

It is evident from the literature cited that there has been a significant focus on the factors that impact on innovation within and among organizations and the models of successful innovation processes. However, relatively few studies address the impacts of contextual factors in project-based industries like the construction industry. One reason might be the unique characteristics of the construction industry such as its fragmentation, reliance on multiple firms to produce a product, project-centre focus and traditional separation of design and construction functions. Additionally, the difficulties in extending an innovation on one project to another due to the customization of each project and different owner/clients on each project may make innovation within construction different from other industries. One study by Ortt (1998) found that the idea that there is a single mainstream innovation approach does not match with the successful approaches that companies have adopted, and suggests that what is required is a contextual approach that accounts for project-level factors. Some contextual factors have been identified. Interviews by Laborde and Sanvido (1994) of people involved in six successful innovations led to the identification of several factors related to the compatibility of organizations within the project, project size and competency of project stakeholders. These factors are confirmed in studies by Kotler (2002) and McQuarter *et al.* (1998) who additionally identify the type of industry being served and geographical location as key contributors to innovation also.

In addition to identifying the individual, intra-organizational, inter-organizational and contextual factors that influence innovation there has been much effort by the research community to create process models for successful achievement of innovation within organizations. Bernstein *et al.* (1998), for example, identify four key steps: (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) found that the process for innovation can be systematic, and is typically associated with problem solving on specific projects. A variety of other models have been developed that address innovation from different perspectives, such as innovation adopters (Rogers, 1995) and organizational attributes (Subramanian and Nilakanta, 1996).

These internally orientated linear models have been found to be insufficient to describe the innovation process within the context of specific projects. Looking at innovation in five different European countries, Miozzo and Dewick (2002) argue that innovation depends on not only the ownership, management and structure of a firm, but also the relations between firms and collaborations with external sources of knowledge. Swan *et al.* (2003) found that some innovations are realized through strategies centred on constructing a community of practice, looking outward to the immediate stakeholders that allow for multiple paths of communication and knowledge transfer. Furthermore, Damanpour and Gopalakrishnan (2001) found that existing theories and process models of organizational innovation are not supported by empirical studies. Therefore, analysis of inter-organizational relationships, diffusive networks and the relative impacts of project-specific factors is required to produce refined models for project-based industries such as construction (Taylor and Levitt, 2005).

Finally, metrics for assessing the success and impact of an innovation have been identified and discussed in literature but practical application and, more importantly, validation of these metrics is limited. Egbu (2001) and Tucker (2004) suggested tracking innovation success by measuring the following indicators: the percentage of profit/sale derived from the innovation; the number of new products/solutions introduced (rate); the number of innovative ideas generated; the number of man hours put into an innovation; and the number of patent submissions. Dikmen *et al.* (2005) built upon these studies by identifying the following leading indicators of innovation: objectives of the firm, required and available resources, and government incentives. However, quantitative research that positively connects specific metrics to innovation is lacking.

The present study builds upon the existing body of knowledge on construction innovation in several ways. The first research objective was to confirm known, and identify new, project-specific characteristics and contextual factors for successful innovation on construction projects. This objective validates and advances the existing body of literature. The second objective was to assess relationships between potential leading indicators of project success and innovation outcomes (i.e. lagging indicators of project success) to identify innovation metrics. This objective specifically focuses on improving the validity and expediency of the metrics suggested by Egbu (2001), Tucker (2004) and Dikmen *et al.* (2005).

Research methods

To achieve the research objectives, case studies were conducted of multiple ongoing and past construction projects. Findings from the literature review and an initial industry survey to validate and supplement the current body of knowledge were used to create the propositions for, and structure of, the case studies. Specifically, the case studies were designed to identify the impacts of project-specific and contextual factors on the development of innovative products, processes or technologies that occurred on contemporary construction projects. The case studies focused on how and why project-specific factors affect the successful generation, implementation and diffusion of new products, processes, technologies and management strategies. According to Yin (2003), case studies are the preferred strategy when, 'a "how" or "why" question is being asked about a contemporary set of events, over which the investigator has little or no control' (p. 9). For this study, the unit of analysis is a construction project.

For consistency, the definition adopted for the study was that presented by Slaughter (1998). Under this definition, innovation includes both the generation of a new product, process, or system and its implementation. A non-trivial change means that the change significantly affects the characteristics of a product or the way it is implemented, or the processes and systems used by a firm. Trivial changes affect only a small portion of the work conducted. Innovation may be the application of a product, process or system that already exists but is just new to the organization adopting it. The innovation must also be diffused beyond just the initial project or setting in which it is employed. The innovation must be used on subsequent projects within a firm or by other firms. Lacking diffusion, acceptance and validation of the change is not demonstrated and the change would be considered simply as problem solving to 'get the job done'.

The nature and complexity of the project and the desires of the owner/client may or may not actively drive a desire for innovation. A forward-thinking client may elect for a radical, advanced facility that incorporates new ideas and challenges the norm. In this case, innovation is planned into the project and is a desired outcome. On the other hand, the impetus for innovation may be for other reasons that arise during the course of the project including: the desires of the architect, engineer or constructor, the need to solve a complex problem posed by the project, and the need to satisfy an external influence such as a regulatory requirement. For the present study, no limitations were placed on the study sample with respect to how the innovations came about or the magnitude of the innovation beyond being non-trivial. The study focuses on all innovation, whether intentionally driven as part of the project goals or not.

Taylor *et al.* (2009) suggest that case study research should attempt to achieve depth by including multiple, polar cases and including multiple, analytically similar cases. Because this study aimed to identify the project-specific contextual factors that affect innovation, multiple projects in two categories were selected for investigation: award-winning and 'regular' projects. It was conjectured that award-winning projects were different from other projects because they were in some way innovative. The recognition given to the award-winning projects was assumed to be reflective of new and unique features on the projects which made them stand out from other projects. While other factors may have influenced their receipt of awards, such as project size, type or architectural design, the peer review process conducted to receive the awards was assumed to account for these factors. 'Regular' projects were identified as those which have not received any recognition for their design and construction. The regular projects were included in the study sample to act as a comparison group and isolate those factors that affect innovation. It was hypothesized that the award-winning projects would contain features or exhibit characteristics that made them innovative, and that these features and characteristics would not be present, at all or to as great an extent, in the regular projects.

The list of award-winning projects was created from regional and national owner, designer and constructor organizations and publications, such as the Design-Build Institute of America (DBIA), Associated General Contractors (AGC), American Society of Civil Engineers (ASCE) and Engineering News-Record (ENR), which regularly give out awards for projects which stand out in their design and construction. The websites of these sources were searched for projects that have received awards in the past five years, from which a list of 20 award-winning projects was created. The 20 projects were selected from the following sources: ASCE Outstanding Projects and Leaders (OPAL) award; DBIA national design-build award; Greatbuildings.com; Oregon.gov Great Buildings of the Year; Buildings.com; Construction Innovation Forum (CIF) NOVA award; and the American Institute of Architects (AIA) Honor Awards.

The list of regular projects was created using Engineering News-Record (ENR). ENR regularly posts advertisements for projects of all different types, sizes and locations that are out for bid. Issues of ENR from the previous five years were reviewed and a list was created of all of the projects advertised in the issues. Twenty projects were randomly selected from this initial list using a pseudo random number generator in Microsoft Excel.

The lists of 20 award-winning projects and 20 regular projects were combined to create a sample of 40 projects. From this combined list, a total of 20 projects were randomly selected to be case studies. This sample size was selected based on study funding and time constraints. Information about the 20 case study projects, including contact information, was collected via the websites described above. Interviews of multiple project personnel were also conducted to gather detailed project information. Project team members at various levels and positions within the owner/client, designer and constructor organizations were targeted. This multi-perspective focus is warranted given the different abilities of each party to judge each aspect of a project and innovation. These abilities are reflected in the work of Blindenbach-Driessen *et al.* (2010) which reports that project leaders are better informed to assess operational performance, while innovation managers are better at assessing product performance.

An interview template was developed based on the literature review and preliminary surveys that asked for information about: the demographics of the respondent; organizational characteristics; project level practices; the innovative aspects of the project; and the success which the project had related to cost, schedule, quality, safety and other outcomes. For questions that asked for qualitative input, the respondents were asked to provide a rating using a Likert scale from 1 to 5 (e.g. 1 = minimal and 5 = extensive). Open-ended questions were also posed to allow the respondents to qualify and provide more depth about their answers. This template was created and utilized on all projects to enhance external validity and reliability.

Several propositions were created which were tested by conducting the case studies. The first proposition was:

> Proposition 1: Owners exhibit great influence over the innovative capacity of construction projects through their funding strategies, criteria for selecting team members, project delivery method selected, and their stated and demonstrated commitment to innovation.

This proposition was created because literature indicates that availability of resources, a climate of collaboration, shared values among project participants and the commitment of managers all contribute greatly to the generation and development of technical innovation (Tatum, 1986a, 1986b; Slaughter, 1993, 1998; Bossink, 2004). Owners and their representatives and agents are in a unique position to affect all of these variables on typical construction projects.

The literature review indicated that inter-organizational collaboration, reduced fragmentation among team members and overlap of the design and construction phases all contribute greatly to the potential for development and successful implementation of innovations. Using this as a starting point, a second proposition was developed as follows:

> Proposition 2: Project delivery and contracting methods that encourage phase overlap (e.g. design-build), shared goals and flexible contracting strategies have a greater potential than traditional design-bid-build, lump sum fixed bid projects to achieve innovation success on construction projects.

The third and final proposition was also developed as a result of the literature review and initial surveys. While there is very little literature that identifies leading indicators that can be used to predict innovation success and methods of measuring and tracking innovation progress on construction projects, the results of the preliminary survey indicated that there are many leading and lagging indicators that should be explored in the context of specific construction projects. This finding led to the third proposition:

> Proposition 3: The aggregation of specific characteristics of construction projects can be used to quantify the innovation potential for a project and this value correlates positively with metrics of innovation success (i.e. lagging indicators).

These three propositions were tested using a case study research process guided by literature on case study research design. There were several aspects of the design of this multiple case study approach that were implemented to improve the internal validity, external validity and reliability of the results and conclusions. The consistent suggestions for ensuring academic rigour described by Yin (2003), Taylor *et al.* (2009) and Eisenhardt (1991) were used as guidance for the design, implementation and analysis of the case study process. According to Yin (2003), the three aspects of the design, implementation and analysis of case studies that contribute to the rigour of the results and conclusions are the construct validity, internal validity, external validity and reliability. Construct validity was preserved by: using multiple sources of evidence on all projects such as interviews, newsletters, awards received, descriptions of project-specific innovations and observations of the project when possible; involving multiple researchers in the collection and interpretation of case study data; and interviewing multiple personnel who served different roles on the construction project (e.g. owner's representative, designer, subcontractor). Pattern matching and collective data analysis that included all case projects were used to ensure the internal validity of the study. External validity was enhanced by: using theory and propositions built from literature and a comprehensive, representative preliminary survey; replication of research methods and sources of data on all projects; and random selection of non-award-winning case study projects. Finally, the researchers used case study protocol that can be replicated by future researchers to ensure reliability.

Results

The efforts to contact personnel involved in the 20 case study projects resulted in a total of 10 completed case studies (50% response rate). For those projects on which data were not collected, the contacts either did not respond or said that they were not interested in participating in the study. A summary of the 10 case study projects is provided in Table 1. Seven of the 10 projects (70%) were from the original award-winning list and the remaining three (30%) were from the regular projects list. All of the case study projects, except one (Project I), were building construction projects. A total of 23 interviews were conducted on the 10 case study projects. Interviews were conducted with the owner (client), architect/engineer of record, general contractor, subcontractors and construction managers. In each case, significant efforts were made to interview as many people as possible and especially those from the owner, architect/engineer and constructor organizations. In every case, people involved in the innovative efforts on the projects were targeted for interviews.

During the interviews the participants were asked to identify what was innovative about their project. The researchers evaluated each of the identified innovations to determine which fit within the definition of innovation adopted for this study. Those that met the definition were:

- Combined system of green design and construction features (Project A). Collection of all of the most 'green' elements into one structure including Durisol block, vegetative roof, few interior walls, clerestory windows, 'short basement' insulating concrete forms and solar panels. This

Table 1 Project case study demographics

Project	Location (state)	Size	Type	Delivery method	Funding source	Status	Innovation score
A	OR	Small	New	DB	Private	Award	60
B	MI	Large	New	CM/DB	Private	Award	59
C	NV	Medium	New	DBB	Public	Regular	21
D	CA	Large	New	DB	Private	Award	49
E	FL	Medium	New	DBB	Private	Regular	10
F	WA	Large	New	DBB	Private	Award	59
G	GA	Small	Renovation	DB	Public	Regular	11
H	MD	Medium	Renovation	DBB	Public	Award	35
I	MA	Large	Renovation	CM/DB	Public	Award	36
J	CA	Medium	New	DBB	Private	Award	–

green system was designed such that all components worked in concert.

- Heat transfer systems embedded in the rock formations below a building (Project A). Heating system that uses the sun to heat water for household space heating, energy-recovery ventilators transfer heat from the water to forced air. Hot water is also pumped into 380 feet deep cores in the basalt bedrock to store the heat until winter. During the winter the heated water is recovered.
- A 'living' roof (Project B). Designed as the world's largest ecologically inspired living roof, about 500 000 square feet, the roof holds several inches of rainfall and as a result dramatically affects the local area watershed.
- Phytoremediation through selected plant types and location (Project B). The use of natural plants at key points around the grounds rids the soil of contaminants present on the site and created by the use and operation of the facility.
- Precast, prestressed concrete frame for seismic regions (Project D). At 39 stories and 420 ft (128 m) high, the building is the tallest concrete structure in addition to being the tallest precast, prestressed concrete framed building in a high seismic region. It is the first major high rise building to be braced by an architecturally finished, exposed precast concrete ductile frame. The reinforcement used to create the seismic ductile frame includes post-tensioning and high strength reinforcing steel. All of these features represent a major milestone in the development of precast/prestressed concrete.
- A new 'organic' inspired structure (Project F). One of the project's unique features is the invention of a new 'organic' structure based on the concept of the human rib cage. At the time of its design and construction, no existing structural system could meet the curvature demands of the architecture. To make the curvature of the structures viable, structural engineers incorporated existing technologies including bridge technology and specialized girder fabrication methods. Curved members were created by specialty manufacturers who used specially designed equipment for creating structural and architectural elements.
- Unique 3D imaging during design (Project F). 3D imaging during the design of the project and unique translation to 2D drawings were first of their kind when this project was designed and built. Also the coordination among the project team members was unique in that the designers needed to communicate 3D concepts to construction workers who are used to viewing plans in 2D.
- Internal temporary bracing design (Project H). The major innovation on this project was the use of specialized internal shoring to brace the interior walls as the beams and internal elements were removed.
- Ground freezing (Project I). The tunnel wall on a very large project was specified to be held back by wood, nail boards and face plates. Unfortunately the soil material was highly organic and 'soupy', and did not hold up well. Instead, the contractor utilized ground freezing by circulating a refrigerated coolant through subsurface pipes to stabilize the soil during construction. The innovation is related to the scale of the application. This process had been used on a very small scale, but had never been used on such a large scale.
- Unique base isolation system for seismic performance (Project J). Base isolation has been utilized on projects and is becoming more popular. The particular base isolation system on this project was designed specially to take into consideration the unique geometrical shape of the facility. The design of the 198 isolators is so complex that none of the concrete forms could vary by more than 1/16th of an inch.

In addition to interviews, newsletters and other archival data from each project were collected and analysed, observations were made on active projects, and drawings, schematics, photographs and other descriptions of innovations generated on the projects were collected.

As can be seen from the list of innovations, two of the 10 innovations identified (internal temporary bracing and ground freezing) were a result of the complex issues presented on the project and the need to complete the project. For the other eight innovations, the project team members intended to innovate on the projects from the beginning. While the definition of innovation employed for the study excludes solutions just to 'get the job done', the researchers felt that the bracing and ground freezing innovations had diffused beyond the projects to integrate into and change construction practice. Therefore these two innovations were included in the study.

The multiple sources of innovation confirmed the three stated propositions. In fact, the project owner's influence was identified as the most essential influencing factor on all innovative case studies. The owner's vision, personal involvement and expertise, inclusion of innovation as a project goal, and level of investment of resources in innovation were commonly cited in participants' responses as essential to the entire innovation process. The ability of upper management to facilitate and promote innovation was also frequently cited as a primary enabler for both idea generation and implementation. These findings provide strong evidence confirming Proposition 1. Further evidence for this proposition is provided in the analysis and conclusions sections below.

Other factors that enable innovation which were frequently cited in the case study interviews are: sufficient time and resources available to explore innovative ideas; active, face-to-face and oral communication; personal involvement of an innovation 'champion'; project delivery methods that allow for overlapping of the design and construction expertise areas; a champion for each innovation to see that it is developed and used throughout the industry; developing a repository for lessons learned; and open collaboration among the project team members. These factors are analysed and discussed in the following section.

Analysis and discussion

Both quantitative and qualitative analyses of the case study results were conducted. For open-ended questions in which the case study respondents provided a narrative response, the researchers reviewed the responses and recorded trends based on the frequency of response. This was done to identify key concepts and terms and to develop an understanding of the similarities and dissimilarities between the techniques used on the projects. For quantitative, closed-ended questions, statistical analyses based on frequency comparisons and simple inference tests were used. Finally, the case study projects were scored by the researchers in terms of their success at innovation, and the best practices identified were correlated with the 'innovativeness' of each project. This combination of quantitative and qualitative analysis of case study results is suggested in literature, e.g. Taylor *et al.* (2009).

Presence of innovation (lagging indicators)

Innovation is identified by positive change in a process, product or system. The change that occurs is a result of the innovation. One way to directly measure innovation is to measure change in the way a project is designed, constructed and delivered from traditional means. Comparing a present state to a previous state allows for determining whether change has occurred. If the change is positive, a result of a new idea or concept, and is significant (i.e. non-trivial), then it would be considered innovation. Hence, the research efforts focused on determining if unique change occurred and if the change was non-trivial. Change was evaluated relative to the following indicators:

- the number of feasible new ideas implemented over the course of the project;
- the number of feasible new ideas generated and tested;
- the extent to which and speed with which a new product, process or system has diffused throughout a firm or the industry;
- the amount of new training and education that is required for employees as a direct result of changes in their work; and
- the extent to which profit, cost, schedule, safety, quality, market share and competitiveness were impacted.

As can be seen in the above list, the impact of the change can be at the project level, across the organization and/or extend out to the industry. That is, the innovation that occurred on a project may affect not only project-level attributes, but the organization and industry as well through diffusion beyond the project. The strength of the relationship between each factor cited above and innovation varies. The amount of change that occurs, the number of new ideas implemented and the extent of diffusion are direct indicators of innovation. The amount of new training and continuing education required is an indirect indicator but closely tied to innovation. It is assumed that the additional required training and education would not be needed if innovation did not occur. The impact on profit, cost, schedule, safety, quality, market share and competitiveness are indirect indicators as well, and more difficult to quantitatively tie to innovation.

It is important to note as well that almost all of the innovations identified are related to the final product as opposed to the design and construction process. This supports prior research (Damanpour and Wischnevsky, 2006) that found product innovations to be adopted at a greater rate than process innovations. However, a study involving a different distribution of innovations (e.g. more process innovations than product innovations) may lead to alternative findings. In addition, given that almost all of the case study projects were building construction projects, a study involving a different distribution of project types may give different results. The organizational environment, mix of trades, level of complexity and other project type factors of building projects often differ from other types of projects and may affect innovation on the projects.

To determine the extent of innovation on the case study projects, each of the lagging indicators described above was interpreted and evaluated by multiple researchers on each project. For the primary indicators (extent of change on the project, number of new ideas implemented, amount of new training and education and extent of diffusion), a scale of 1 to 10 was used with

1 indicating none and 10 indicating significant/extreme. All of the projects selected for the study were built within the previous five years. Therefore, for the evaluation, the extent of diffusion beyond the project was limited to that which occurred within five years. Some innovations may diffuse at a slower rate than others which, as a result, impacted on the evaluators' assessment. For the analysis, diffusion was defined as translation of the product, process or technology beyond its first use to other projects, firms or industry domains. The researchers assessed the extent to which diffusion had occurred using the input provided by the interview participants and the researchers' own knowledge of the industry and investigations into the innovation.

For assessing the secondary indicators (project, cost, schedule, etc.), a 1 to 5 scale was used (1 = none; 5 = significant/extreme). A lower scale was used for the secondary indicators because of the likely possibility of confounding factors and the uncertainty whether innovation was the driver of the impact. To determine the final ratings for each indicator, the researchers used a multi-step evaluation process utilizing the researchers' individual and collective knowledge of innovation, the construction industry and construction projects. The researchers independently reviewed the documentation for each case study and evaluated each indicator using the 1 to 10 and 1 to 5 scales mentioned above. The researchers then discussed as a group each case study project in depth and came to a consensus on the appropriate rating for each indicator.

Each case study project was rated based on all of the indicators and the ratings were summed to create an innovation score for the project (see Table 1). The innovation scores ranged from 10 to 60, with a mean score of 37.8 (median = 36), where a higher score indicates greater innovation. On one of the projects, Project J, insufficient reliable information was available to evaluate the lagging indicators and, therefore, no innovation score was calculated for this project. The mean innovation score for the award-winning projects was 49.7, and 14.0 for the regular projects. It is evident that the award-winning projects had a greater amount of innovation; however, the difference was not found to be statistically significant (Wilcoxon Rank Sum Test, two-sided p-value = 0.27). The results are moderately strong given the small sample size and the fact that the data are based in large part on interviews.

Innovation enablers and impacting factors (leading indicators)

The next step in the analyses involved investigating the relationship between individual enabling and impacting factors (leading indicators) and the innovation scores calculated from the lagging indicators. Each leading indicator was considered to be an explanatory variable whereas the sum of the lagging indicator scores (Table 1) represents the response (i.e. dependent) variable. In this analysis, multiple linear regression models were created and the extra sum of squares F-test was used to identify the statistical model that best represented the data as suggested by Ramsey and Schafer (2002). After testing complex multiple linear regression models which included interactions among explanatory variables, the extra sum of squares f-tests indicated that simple linear regression models were most appropriate (p-value = 0.04). During this analysis multicollinearity was tested to ensure that there were no confounding relationships among explanatory variables. The results of this test indicated that the tolerance was less than 0.20 for all interactions among explanatory variables and the variance inflation factor never exceeded 4. This indicates that there is no statistically significant multicollinearity among the leading indicators (Ramsey and Schafer, 2002).

Owner influence

The case study interviews asked four questions which can be used to gauge the influence of the owner on innovation: (1) To what extent was the owner involved or interested in innovation? (2) To what extent did the owner allow time to develop innovative ideas? (3) To what extent was innovation a project objective of the owner? and (4) To what extent did the owner include innovation in the budget? Based on the responses to these questions from all parties interviewed (owners/clients and others), the researchers rated the projects, using a scale of 1 to 10, according to the influence of the owner on innovation. A comparison was made between the owner influence rating and the innovation scores previously calculated for each case study project (see Figure 1). A very strong, positive relationship exists between owner influence and innovation ($R^2 = 0.91$; p-value < 0.001; $\beta = 5.41$). This finding departs from some prior research that has identified potentially negative effects the owner/client might have on innovation (Ivory, 2005). Using construction project case studies, Ivory found that strong client leadership may suppress the sharing of ideas and create an overly narrow focus of particular types of innovation, both of which have negative consequences for innovation. It should be noted that the findings in this study may not be inconsistent with Ivory (2005) because the present study investigated the relationship between owner interest and investment in innovation. Careful consideration needs to be given to the amount and nature of influence that the owner has over a project.

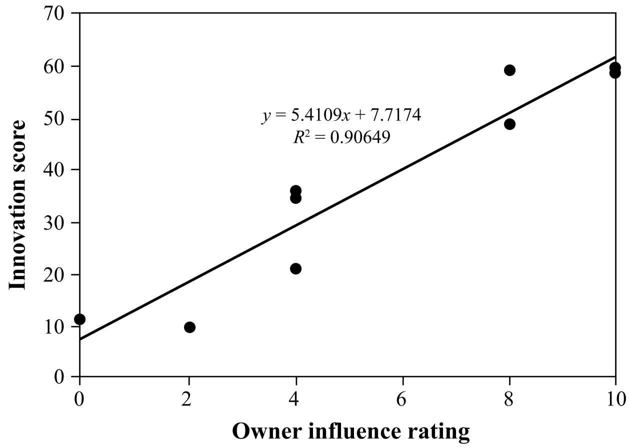

Figure 1 Impact of owner influence on innovation

Presence of an innovation champion

The case study participants were asked to rate the extent to which there was a champion on the project shepherding the innovation and eliminating potential roadblocks. When comparing the relationship between the presence of a champion on the project and the project innovation scores, the case study projects show a moderately strong relationship (R^2 = 0.79; p-value = 0.001; β = 12.07). Those projects which reported greater involvement of a champion to shepherd the innovation and eliminate roadblocks also experienced innovation. In fact, the regression coefficient indicates that this is the most impactful factor.

Lessons learned/knowledge management

The research investigated the impact of a lessons learned/knowledge management system on innovation by asking the four questions: (1) Does your firm have formal mechanisms to *capture* lessons learned and to what extent are the mechanisms implemented? (2) Does your firm have formal mechanisms to *disseminate* lessons learned and to what extent are the mechanisms implemented? (3) Does your firm have formal mechanisms to disseminate innovations and to what extent are the mechanisms implemented? and (4) Does your firm implement lessons learned on future/subsequent projects and to what extent are the lessons learned implemented? The responses were used to determine an aggregate lessons learned rating for each case study project. The analysis revealed a moderately strong, positive relationship between lessons learned and the innovation scores (R^2 = 0.79; p-value = 0.001; β = 8.12). These results confirm the findings of Chinowsky *et al.* (2007) and Chinowsky and Carillo (2007).

Upper management support

In a preliminary survey, upper management support was the most commonly identified factor that enables innovation. In the case study interviews, upper management support was investigated through seven questions: (1) To what extent is innovation part of your firm's organizational strategy? (2) To what extent is innovation part of your firm's mission statement? (3) To what extent is innovation part of your firm's business plan? (4) To what extent is innovation part of your firm's budget? (5) To what extent does your firm hold innovation meetings? (6) To what extent were employees allotted time to explore new ideas? and (7) To what extent does your firm market innovation? Similar to other leading indicators, an aggregate upper management support rating was calculated based on the interview participants' ratings in response to these questions. A comparison of upper management support to the innovation scores on the project reveals a moderate to strong relationship between upper management support and innovation for the case study projects (R^2 = 0.79; p-value = 0.001; β = 7.36). This finding shows that upper managers serve an important role in developing and sustaining an environment conducive to innovation and extends the findings of Hausman (2005) and Lee *et al.* (2005) to include project innovation in addition to organizational innovation.

Research and development

Research and development (R&D) of new concepts, technologies and processes is instrumental in the innovation process. The case study interviews used four questions to assess R&D: (1) To what extent does your firm perform R&D? (2) To what extent does your firm include R&D in project budgets? (3) To what extent was there time allowed for R&D on this project? and (4) To what extent was R&D supported by your firm for this project? The term 'R&D' was meant to represent the commonly held description of the process: investigation of a new idea and development of a tool or resource for practical application of the idea. It was assumed in the interviews that the participants held this same understanding of the term; no effort was made to verify whether the participants' understanding differed. Similar to the other leading indicators, aggregate ratings were calculated based on the responses to all four of the questions. A very strong, positive relationship (R^2 = 0.89; p-value < 0.001) was found between R&D and innovation. The ability to perform R&D activities, however, may be difficult for some firms especially in such a project-based industry as construction. It is often difficult for firms to pursue R&D on current projects given the constraints of project objectives and goals. If a firm is interested in innovating, it may find that current projects are obstacles to doing so, and not have the resources or opportunity to conduct the necessary R&D elsewhere. Support from the owner/client for the innovation is often a necessity.

Organizational climate

Part of what makes up an organization's culture is the climate (or environment) in which the employees work. Climate is characterized by the employment surroundings, both physical and organizational, within which the employees act. Examples of factors that affect organizational climate with respect to innovation include upper management's emphasis on innovation and whether formal recognition is given to those employees who innovate (Schein, 1999; Lee *et al.*, 2005). The case study data gathered allowed for assessing the impact of organizational climate on innovation. An assessment of the organizational climate was developed using a combination of five of the leading indicators described above: project team collaboration, degree of project team integration, communication, upper management support and employee recognition. Each of these indicators is viewed as having an impact on the work climate that employees experience with respect to innovation. The participant response ratings from the case study interviews for these five indicators were summed to create an organizational climate rating for the project. The data show a very strong, positive relationship between organizational climate and innovation ($R^2 = 0.88$; p-value = 0.004; $\beta = 1.91$).

Organizational structure

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. The benefit of having mechanisms which eliminate such barriers and facilitate communication and sharing is supported by Bosch-Sijtsema and Postma (2009). In a study of how firms in the construction industry cooperate, Bosch-Sijtsema and Postma found that cooperation, mutual sharing of knowledge and mutual access to knowledge enable innovation. The following leading indicators were used to calculate an aggregate organizational structure score from the case study interviews: presence of an innovation champion, lessons learned/knowledge management, upper management support and research and development. Each of these indicators plays a part in establishing the organizational structure with respect to innovation. The participant response ratings from the case study interviews for these four indicators were summed to create an organizational structure rating for the project. The data show a very strong, positive relationship between organizational structure and innovation ($R^2 = 0.90$; p-value = 0.002; $\beta = 2.00$).

Other predictive variables were found to have larger residuals and less statistical validity including project team collaboration ($R^2 = 0.70$), degree of project team integration ($R^2 = 0.52$) and communication ($R^2 = 0.63$). Previous literature identifies employee recognition as important to innovation; however, insufficient data were gained in the case study interviews for the research team to develop a reliable rating of employee recognition on the case study projects.

Predicting and measuring innovation

The analysis indicates that there are many organizational factors which affect innovation at the project level. The findings also confirm the large body of literature that discusses organizational innovation. The statistical tests show that each of these factors independently affects innovation to some extent on its own. Measuring the extent to which each factor is present on a project and within a firm can provide a means to predict the level of innovation that occurs. When considered together, the factors can be used to more accurately predict innovation. This is illustrated in Figure 2 which shows the relationship between the combined leading indicator scores (the sum of all of the ratings for the different leading indicators) and innovation scores on the case study projects. These data reveal a very strong, positive relationship between the indicators and innovation ($R^2 = 0.91$; p-value < 0.001; $\beta = 0.94$). Despite the relatively small sample size, several statistically significant results were obtained due to the strength of the correlation between the predictor and response variables. The researchers also ensured that other forms of data such as observations supported the statistical conclusions. Because of the small sample size, the results should be considered indicative of potential relationships and further research should be conducted on this topic to validate the findings.

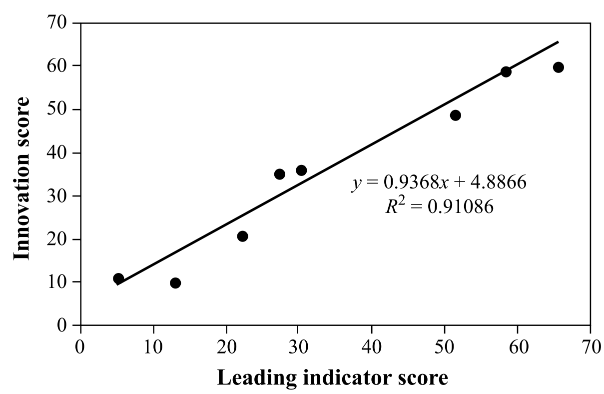

Figure 2 Impact of leading indicators on innovation

Table 2 Means for evaluating innovation leading indicators

Leading indicator	Means of evaluation
Owner influence	• Extent to which innovation is an objective of the owner • Level of support (monetary, time, encouragement, etc.) given by the owner to innovation on the project
Innovation champion	• Presence of a champion, sponsor, or initiator for an innovation, or for innovation within a project or firm • Percentage of the innovation champion's role and responsibilities that include innovation
Project team collaboration	• Use of a centralized project office where all participants work in a common setting • Level of involvement of project team members in project meetings, constructability reviews, value engineering and quality control efforts
Project team integration	• Use of an integrated project delivery method (e.g. design-build) • Extent to which multiple project team members worked as a team • Extent to which different disciplines are involved in each project function • Whether the design and construction phases overlap • Diversity of the project team
Communication	• Extent to which communication channels are open • Extent to which communication is cross-discipline • Extent to which communication is encouraged and proactive • Extent to which communication is not unilateral • Extent of face-to-face communication
Lessons learned/ knowledge management	• Presence of a lessons learned process and programme • Extent to which lessons learned are captured and disseminated • Extent to which innovations are disseminated and used on subsequent projects
Upper management support	• Innovation as part of organizational strategy, mission statement and business plan • Whether innovation is part of the project and firm's budget • Extent to which innovations are used in marketing the company • Level of resources (monetary, time, etc.) devoted to innovation • Extent to which R&D is supported by upper management
Research and development	• Extent to which the firm performs R&D on potential new products, processes and systems • Presence of an R&D budget • Allowance of time to research and develop new products, processes and systems
Employee recognition	• Whether employees are recognized for their contributions to innovation on a project • Type and value of the recognition provided

Taking the study findings from research to practice requires recognition of design and construction practices and the characteristics of the construction industry. Measuring each leading indicator on a project may in some cases be difficult because of the nature of the indicator and the characteristics and capabilities of the project and firm. The influence of the owner, for example, cannot be directly measured and may be affected by many factors. Assessing several indirect factors may provide a feasible means of measuring owner influence accurately. On the other hand, the presence of an innovation champion would be easier to measure. Suggested ways to measure the leading indicators in practice are provided in Table 2. While measuring leading indicators can be difficult, measuring and tracking the identified lagging indicators is relatively easy. When measuring lagging indicators, it is important to compare the measurement to a benchmarked value to get a sense of the magnitude of change.

Conclusions and recommendations

In its simplest form, innovation is positive change as a result of new ideas. While a perception exists that innovation in the construction industry is lacking, decreasing cost and schedule, improving productivity, quality and safety, and meeting or exceeding projected goals often require innovation. This is true for construction as well as other industries. Innovation within a project, company and occupational industry provides the opportunity to realize significant benefits and, in a competitive market, is a requirement for continued existence. All companies must innovate at some level in order to stay competitive. Innovation in the construction industry may take place at a lower 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.

As indicated previously, one aim of the study was to validate existing knowledge of factors within and among organizations at the project level that enable and impede innovation, and determine additional factors if possible. Enablers of innovation were found to include: support from upper management, good communication within the firm, and the overlap of design and construction phases that is common within integrated project delivery methods. All of these enablers were identified in previous research (Tatum, 1986a; Slaughter, 1993; Bossink, 2004). Barriers to innovation however, can, and do, exist at the project, organization and industry levels. Some of the barriers, which were also found in prior research (Slaughter, 1993; Egbu, 2001), include: aversion to risk/change, lack of resources, low return on investment, and strict regulations and codes. For encouraging innovation and overcoming barriers to innovation, the climate and structure of an organization and project were identified as impacting factors. An open, accepting and positive organizational climate surrounding the workplace encourages the generation and acceptance of new ideas. Similarly, an organizational structure that highlights and supports efforts to explore and try new ideas as a core value and strategy also benefits innovation. These findings confirm previous research (e.g. Burns and Stalker, 1961; Chandler *et al.*, 2000) which identifies the attributes of organizational climate and structure as being important to successful innovation. Finally, the single most important factor for influencing all of these factors on a construction project was the demonstrated commitment of the owner/client. While having a champion was the most impactful factor according to the statistical analyses, qualitative input from the case studies indicated that owner influence played a stronger role.

The study also aimed at identifying leading and lagging indicators that can be used to measure innovation potential and success, respectively. Those project-level leading indicators that were found to have a strong positive relationship to innovation on the project were: owner/client influence, presence of an innovation champion, presence of lessons learned/knowledge management system, upper management support for innovation, and extent to which R&D is supported. These leading indicators add to those previously identified by Dikmen *et al.* (2005). The inclusion of lessons learned/knowledge management as a leading indicator supports similar findings by Chinowsky *et al.* (2007) and Chinowsky and Carillo (2007). The results of the present study are limited by the small sample size, and may not be generalizable outside the types of projects and innovations studied.

The three propositions tested by the case studies were all supported to some degree. Proposition 1 (owners serve a pivotal role in the innovative capacity of a project), was confirmed with extremely strong evidence from the case studies. The second proposition (project delivery and contracting methods that encourage phase overlap contribute greatly to innovation) was moderately supported. The case studies revealed that organizational attributes that contribute to culture and structure had a greater influence on innovation success than project-specific factors such as phase overlap. However, the authors recommend further investigation of project delivery and contracting methods in regard to their connection to innovation. While the present study found only moderate support for innovation, these methods can be structured to promote the integration of design and construction expertise on a project and communication among the team members. Such integration aids in creating a multi-functional team, establishing a collaborative environment, and enabling an intentional, innovation-seeking plan on a project. These methods also support the mutual sharing of knowledge and benefits which are shown to have a positive impact on innovation (Bosch-Sijtsema and Postma, 2009).

Finally, the third proposition (leading indicators can be identified and correlated with innovation success) was strongly supported by the quantitative and qualitative analyses of the case study data. In addition to the findings associated with the propositions, there were collateral findings related to specific organizational characteristics that affect innovation (e.g. upper management support and formal recognition of innovation) that confirmed literature such as Wolfe (1994), Hausman (2005) and Lee *et al.* (2005). The case study analysis did not indicate the extent to which innovation brokers are a leading indicator. However, further work associated with innovation brokers as suggested by Winch and Courtney (2007) is recommended to study their impact and involvement at the project level.

Measuring and tracking innovations were identified as being important to the study participants. However, the respondents felt that their firms' ability to measure and track innovations was low to moderate. This perhaps is recognition of a lack of metrics, difficulty in measuring innovation, or a lack of tools available to assist in measuring innovation. The construction industry would benefit from the availability of a guideline or tool to assist firms in this process. The process of innovation involves different components and activities to generate new ideas and bring them to reality. Innovation in the construction industry requires three components: *idea generation*, *opportunity* and *diffusion*. Each component is important to the innovation process and all three components must exist in order for innovation to occur and thrive.

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