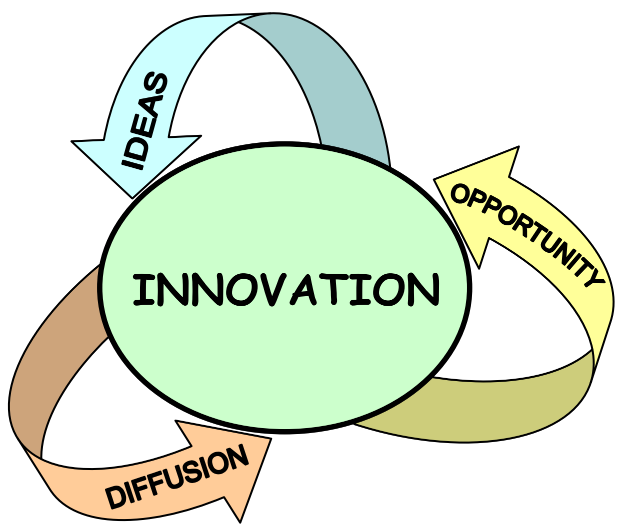
Energizing Innovation in Integrated Project Delivery Research Project

Final Report



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ENERGIZING INNOVATION IN INTEGRATED PROJECT DELIVERY

FINAL REPORT

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EXECUTIVE SUMMARY

Innovation is a term used frequently in the construction industry. It is the desire of many owner, design, and construction firms to be innovative in the services and products which they provide on projects. Some projects, and as a result firms, are recognized as being more innovative than others. Understanding what affects the innovation process and how innovation can be enhanced is a key step in attaining the goal of innovation in the construction industry.

This document is the final report of a research study to investigate innovation in the construction industry. The study, titled "Energizing Innovation in Integrated Project Delivery", was jointly funded by a partnership between the Design-Build Institute America (DBIA) and the Charles Pankow Foundation (CPF), and conducted by Oregon State University (OSU). The goal of the research is to enhance the ability of the construction industry to innovate in its delivery of construction projects through integrated project delivery processes. To meet this goal, the study aims to determine: the factors that impact innovation on a project; how these factors can be used to measure the level of innovation on a project; and the practices and processes that encourage and facilitate innovation.

For the purpose of the study, the following definition of innovation was adopted: "Innovation is 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". Under this definition, innovation includes both the generation of a new product, technology, or process, and its implementation. Additionally, innovation may be the application of a product, technology, or process that already exists but is just new to the organization adopting it.

The research activities began with a review of relevant literature followed by three data collection activities. The first activity was an initial benchmarking survey. An on-line questionnaire soliciting information about innovation in the industry was distributed to the memberships of DBIA and the AGC Oregon-Columbia Chapter, and to individuals with a strategic role in their firm (i.e., management) selected from outreach contact lists of the OSU Construction Engineering Management Program and personal contact lists of the researchers. To supplement the on-line portion of the survey, interviews were conducted with construction industry personnel to gain greater detail about innovation in the industry. A total of 79 survey responses were recorded from the on-line questionnaire (69) and the interviews (8 A/E's, 9 GC's, 3 sub's, 1 supplier, 3 owners/developers, and 3 other). The responses came from a wide cross-section of personnel and organizations located in 21 states across the U.S.

The benchmarking survey was followed by a survey of firms which have developed innovative products to investigate innovation at the product development level. A list of innovations was created from the Construction Innovation Forum's NOVA Award website and the Emerging Construction Technologies website. A questionnaire similar to that used for the benchmarking survey was e-mailed to 189 of the firms, from which 34 responses were received. The innovations developed by the responding firms can be grouped into the following categories: information technologies (3), computer-based technologies (3), construction equipment (6), construction means and methods (8), and facility end products (14).

The last data collection activity is case studies of construction projects. A list of 20 "award-winning" projects was developed from projects that were regionally and nationally recognized by key industry owner, designer, and constructor groups (e.g., CERF, AGC, and ASCE). In addition, 20 comparison projects were randomly selected from those listed in ENR over the past 3-5 years and added to the list of award-winning projects. From this combined list, a total of 20 projects were randomly selected to be case studies. Multiple personnel on ten of these projects agreed to be interviewed. The ten case study projects represent a wide cross-section of different project types and are located in nine states across the U.S.

Innovation provides benefits that are recognized at both the project and organizational levels. These benefits include: increased productivity, cost savings, improved quality and safety, providing a competitive advantage, increased market share, and appearance of new markets. Innovation in the A/E/C industry requires three components: *idea generation, opportunity,* and *diffusion*. All three components must exist in order for innovation to occur and thrive. The research activities and data collected reveal project and organizational attributes that stimulate and impact these components and which can be used to measure innovation.

Idea Generation

Innovation starts with an idea. New ideas are conceived and then developed, implemented, and diffused throughout an organization and the industry. Generating new ideas is facilitated by:

- A propensity to be curious and a drive to "find a better way".
- A mission and surrounding environment conducive to trying and accepting new things (i.e., change) and to always seek to do a better, more efficient job.
- Continued support and motivation to innovate.
- Open and proactive communication across project teams and within a firm.
- Workforce and project team integration and diversity.

Opportunity

Innovation also requires an opportunity to develop, test, and implement a new product, process, or system. Opportunities commonly arise in relation to problem solving on a project or in a firm. Project team efforts to solve unique problems expose and elicit innovative solutions. The opportunity to develop, implement, and evaluate the innovative solutions requires the freedom to do so as well as resources (time, funding, labor, equipment, etc.). Opportunity for innovation is enhanced by:

- A project owner and/or firm upper management with a goal to challenge the status quo, expression of the goal, and actions in support of the goal.
- Commitment of resources and time to explore new ideas.
- Project development systems and contracts that allow freedom and time to try new ideas and which integrate the different disciplines on a project team (e.g., design-build project delivery method).
- A "champion" within a firm or project who supports the innovation and "paves the way" for its development and implementation.

Diffusion

Many innovative solutions come about from the need to solve a problem on a project or within a firm. Innovation, however, occurs when that solution is used on subsequent projects or diffused throughout the industry. Diffusion to other projects and the industry confirms the value of the innovation and leads to positive change. Diffusion is made possible and assisted by:

- A lessons learned program that captures and disseminates organizational knowledge.
- Activities for sharing information across project teams and organizations.
- Working with differing partners (in-house and external) and with different disciplines.
- Workforce continuing education and training.

The research study included the development of resources to assist practitioners in implementing the results of the research. The products created are: an annotated bibliography on innovation; an Innovation Manual of Practice; a slide presentation on the research and innovation for on-line learning; conference and journal papers; and a monograph presenting the significant outcomes of the research. Industry practitioners are encouraged to review and utilize these resources and endeavor to enhance innovation on their projects.

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. Many small changes can eventually lead to a big change. The change is significant if it is positive, regardless of its magnitude. Whatever its size, innovations within the construction industry continue to attract attention and motivate those involved to continually search for how to do it better.

1.0 INTRODUCTION

In 2006, the Design-Build Institute of America (DBIA) and the Charles Pankow Foundation (CPF) jointly funded a research study conducted by Oregon State University (OSU) titled "Energizing Innovation in Integrated Project Delivery." The intent of the study was to determine: the factors that impact innovation on a construction project; how these factors can be used to measure the level of innovation on a construction project; and the practices and processes that encourage and facilitate innovation. The study also included the development of resources for implementation of the research findings in practice. Upon meeting these objectives, the overall goal of the research is to enhance the ability of the construction industry to innovate in its delivery of construction projects through integrated project delivery processes. The research activities were completed in August 2007and accompanying documents finalized in December 2007.

This document is the final report for the research study. This report describes in detail the: research methods used in the study; research findings; analysis and discussion of the findings; conclusions; and recommendations for practical application of the findings and for future research. Included as appendices to the report are the implementation resources developed during the research study. The report is intended to provide DBIA and CPF with a detailed description of the work conducted under the research grant and the research outcomes for documentation and dissemination purposes.

1.1 Background

The term "innovation" is used in various ways. 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." 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 invention and application of the invention. Additionally, innovation may be the application of a technology or method that is within the realm of existing practices but is just new to the organization adopting it. Lastly, innovation is not problem solving on one project. Innovation is systemic, whether it occurs throughout a firm or a work industry.

Innovation within a project, company, and work industry provides the opportunity for significant benefits. Implementing a process, system, or product that is new to the organization that adopts it can lead to decreases in cost and schedule, and improvements in quality and safety. Other benefits as a result of innovation that have been exposed in previous research include an increase in market share, a competitive advantage, and increased technical feasibility of projects (Madewell 1986; Slaughter 1998; Macomber 2002). It is clear from previous research and anecdotal comments from industry practitioners that innovation is a key to continued success and profitability. This is true for the construction industry as well as for all other work industries.

While the prospective benefits from innovation are apparent, there is a general perception amongst some professionals in the construction industry that innovation in construction is rare.

This perspective often stems in part from comparisons of the construction industry to other fast paced and changing industries, such as the electronics and medical industries, and from the barriers to innovation that exist within the construction industry. Such barriers include the traditional contracting method which separates areas of expertise and creates obstacles to the transfer of constructive knowledge and the ability of a project team member to impact the work of other disciplines to positively benefit the project.

Many instances of innovation in the construction industry, however, have been documented by researchers (Slaughter 1998). Innovation does exist and, in some sectors occurs to a great extent. For innovation to occur and thrive, enabling conditions must exist. Research has been undertaken to discover the conditions that promote innovation in construction. Bossink (2004), for example, classifies these drivers as *external*, *industry*, or *enterprise*. External drivers are those stemming from environmental conditions which are imposed on most construction firms. Industry drivers include items that involve relationships among industry peer providers (such as designers and constructors). Finally, enterprise drivers include practices controlled by a distinct firm in the methods by which that firm manages the process.

The problem addressed by this research study is that although attempts have been made to categorize innovation drivers and identify actual instances of innovation, additional studies are needed that discover specific techniques that promote innovation and identify how to measure the level of innovation achieved. Previous studies have focused on individual technologies at the project level, yet the interrelationship among the industry providers is often cited as both an inhibitor and enhancer of an innovative environment. Integrated project delivery offers a broadened relationship between industry providers and is viewed as a means to encourage and attain the benefits of innovation. Hence, examination of innovation in the construction industry within the context of integrated project delivery is needed to understand how to leverage this collaborative process to optimize innovation.

Innovation can be expressed on a project and in an organization in a variety of ways. Addressing the stated problem requires a determination of the indicators of innovation and the magnitude of their impact. This can be achieved through the examination of current literature and of past and current projects that range in their level of innovation. In addition, fundamental to addressing the problem is a comprehensive understanding of the construction industry and integrated project delivery.

1.2 Study Goals and Objectives

The overall goal of this research study was to enhance the ability of the construction industry to innovate in its delivery of construction projects through integrated project delivery processes. Achieving this goal can be accomplished through an increase in knowledge about construction innovation and the development of practices and guidelines to overcome associated barriers and support achieving innovation. Recognizing that the qualities of integrated project delivery processes promote innovation, the environment under which the research was conducted is that of projects delivered using integrated project delivery methods. Meeting this goal required determination of: the factors that impact innovation on a project; how these factors can be used to measure the level of innovation; and the practices and processes that encourage and facilitate innovation. The specific objectives developed for the research study were as follows:

1. Determine the current extent of innovation within the construction industry.
2. Identify incentives that encourage the generation and implementation of innovative ideas.
3. Identify barriers to exploring and implementing new ideas.
4. Identify means for encouraging innovation and overcoming the barriers to innovation.
5. Determine how innovation can be measured and interpreted using a variety of metrics.
6. Create practical guidelines for enhancing innovation on a project.

The research was designed to focus on the U.S. construction industry and incorporate projects that have been completed within the last five years. Projects of different sizes and types, including buildings, heavy civil, and industrial projects, were studied to balance the distribution of projects and reflect the breadth of the construction industry. All aspects of integrated project delivery, including design, construction, and project management, were examined. In addition, an assessment was conducted based on the composition of the integrated project delivery team, i.e., fully integrated vs. joint venture. Accordingly, the intended audience of the research findings is the construction community. It is expected that the construction community will integrate the findings into their project development processes through the suggested practices and guidelines established from the research.

1.3 Research Scope

The research plan for the study was developed based on observations of the interactions among the key players in the construction industry, previous research experience, the opportunities and resources available to the researchers, and the challenges and obstacles to conducting scientifically-based research on construction projects and construction performance. The foundation for the research plan was the analysis of key project data to discover those environments and practices which most encourage innovation. The research was conducted using the survey and case study methods. These methods were selected due to the open nature of the information to be gathered, the diversity of the study population (i.e., the construction industry), and to ensure reliability of information gathered. On-line surveys allow for gaining specific project information from a widely dispersed and diverse sample. The case study method allows for unstructured interview questions, designed to most fully expose potential innovative techniques and allow the researchers to probe further when needed.

The following tasks were the activities planned and undertaken for the research study:

Task 1: *Review Current Literature and Identify Metrics* (May – July 2006)
Task 1 involved a review of literature on innovation and integrated project delivery processes in the construction industry from the following sources: academic and professional journals; industry periodicals; reliable Internet sources; and related industry organizations. The results of the literature review were used to develop a preliminary list of metrics for measuring innovation.

Task 2: ***Investigate Current Innovation and Collect Pilot Data*** **(May – July 2006)**
The second activity consisted of conducting interviews of construction industry personnel to benchmark the current level of innovation in the industry and evaluate the viability of the planned research method. Using the results of Task 1, a set of questions was developed and used as a data collection instrument to maintain consistency in the data collection process and ensure that the desired data is collected. Projects of different types and sizes that are located on the West Coast were selected for this preliminary assessment.

Task 3: ***Preliminary Analysis and Confirm/Update Research Methodology*** **(July – Aug. 2006)**
The pilot data collected from Task 2 was analyzed to develop preliminary findings regarding the current level of innovation in the construction industry, and identify criteria to use to select the case study projects. The proposed research methods were subsequently reviewed and updated where appropriate.

Task 4: ***Prepare and Present Interim Report*** **(July – Aug. 2006)**
An interim report was prepared and submitted for review that documented the results of the literature review, the preliminary interviews, and the findings from the initial efforts, and provided recommendations for the remaining tasks. A slide presentation on the progress of the research was given at the 2006 DBIA Annual Conference from October 18-20, 2006 in Nashville, TN.

Task 5: ***Identify Case Study Projects*** **(Sept. – Oct. 2006)**
A two-part selection process was employed to develop a set of case projects to study. First, a pool of award-winning projects was developed using projects that were regionally and nationally recognized by key industry owner, designer, and constructor groups (e.g., CERF, AGC, ASCE, and other national organizations). The researchers also consulted with DBIA/CPF to identify additional projects across the U.S. to include in this phase of the study. These projects were scored in terms of their innovativeness and a sample of highly innovative projects was selected to become part of the case study sample. The case study sample was then be broadened with a second set of projects completed within the last five years. The selection of this second set of projects was made without regard to innovation scores or awards received; however, there was an attempt to ensure that the projects encompass the range of the successfully innovative projects in terms of key factors such as project type, size, location, contracting method, and interrelationship of the project delivery team. The selection process strove to obtain a balance between projects with different qualities (e.g., buildings, roadways, industrial facilities, etc.) included in the study. The two sets of projects were combined into one study set, and the case study process began. A portion of the original sample was set aside and used to validate the results of the original data analysis.

Task 6: ***Case Study Interviews and Data Collection*** **(Nov. 2006 – April 2007)**
Interviews were then conducted of personnel involved in the case study projects. The interview questionnaire developed, tested, and modified as part of the preliminary work was used to structure and guide the interviews. Individuals representing a variety of disciplines and perspectives on the projects were interviewed. Project information pertinent to the research (e.g., project cost, schedule, contract documents, etc.) was also collected on each project.

Task 7: ***Data Analysis and Validation of Results*** **(Feb. – Aug. 2007)**
The case study data collected was analyzed using the experience and knowledge of the research team and statistical methods. For open-ended questions, the research team extracted the key concepts and terms and developed a list of 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 projects were scored in terms of their delivery of innovation, and the best practices identified were correlated with the innovativeness of each project.

The findings of the research were used to develop best practices and guidelines to assist companies in implementing the study results in practice. The practices and guidelines take into account various project parameters, such as type, size, and project team composition, for determining how best to apply the findings on a particular project. The suggested practices and guidelines were evaluated through industry input. Industry partners who provided information in previous research tasks were asked to review the suggested practices and guidelines and provide comments related to their viability of implementation and effectiveness in promoting innovation. Input from the industry partners was used to modify the practices and guidelines where appropriate for dissemination to the industry at large.

Task 8: ***Prepare and Present Final Report*** **(June – Dec. 2007)**
Task 8 consisted of preparing and presenting a final research report. This document constitutes the final report. The final report describes in detail the research plan, results, conclusions, and recommendations for practical application of the findings and for future research. A presentation of the final research results was also given at the 2007 DBIA Annual Conference & Expo in Dallas, TX.

Task 9: ***Prepare and Submit Draft Monograph*** **(June – Dec. 2007)**
The final task consisted of preparing and submitting a monograph that presents the salient research results in a condensed form for easy review and implementation.

Added Tasks
Following the completion of Task 4, an additional task to study innovation at the product level was added by the researchers to the research. The researchers recognized that much of the innovation that takes place within the construction industry occurs through the introduction of new products and technologies which, in some cases, are developed by manufacturing companies outside the industry. The development of these products goes through the same basic innovation process as the innovation that occurs on projects. Hence, Tasks 5 and 6 were augmented to include a survey of companies which have developed individual innovations. This effort included the selection of innovations using on-line resources and distribution of a questionnaire survey to the developers and manufacturers of the innovations.

1.4 Dissemination and Implementation

In addition to this final report, additional resources were created for on-line dissemination of the research results. A monograph, which consists of a condensed version of this report, was developed to create a concise presentation of the research and findings. A PowerPoint slide presentation that describes the research study, results, and recommendations is available for on-line learning. Using the results of the literature review, an Annotated Bibliography, with links to public domain documents where possible, has also been created for on-line access. The bibliography includes a list of links to websites that provide information on the topics of innovation and integrated project delivery. A list of guidelines and suggested practices was developed from the study to assist with practical implementation of the research findings. Based on the suggested practices and guidelines, a flowchart was developed that allows for identifying appropriate practices that enhance innovation. The flowchart is presented in an Innovation Manual of Practice which is designed as a practical guide to innovation for the construction industry. The content of these documents, and how the documents can be accessed, are described further in Section 7.0 of this report.

Journal papers about the research study are another means by which dissemination of the research findings has taken place. A paper titled “Benchmark of Innovation in the Architecture/Engineering/Construction Industry” was presented at the American Society of Civil Engineers (ASCE) 2007 Construction Research Congress, Grand Bahama Island, Bahamas, May 6-8, 2007. Additional journal papers are expected from the research findings. A summary of the research will also be sent to industry organizations, such as DBIA, AGC, ASCE, and AIA, to disseminate to their members through the organization’s periodic mailings, newsletters, and publications. Lastly, documents that describe the research study, and resources that provide information and guidance to industry practitioners for implementing the research findings, will be given to the Design-Build Institute of America and the Charles Pankow Foundation for posting on-line.

2.0 LITERATURE REVIEW

Task 1 of the research study was to review current literature on innovation. This effort reveals "what we know to date", provides a foundation from which the research can move forward, and provides a guide for the research plan. In addition, the literature found during this effort was used to develop the annotated bibliography on innovation (see Section 7.0 of this report).

The literature review began with an extensive search to uncover literature on innovation with a focus on the construction industry. (Note: The *construction industry* as used in this report is intended to represent the fields of architecture, engineering, and construction). Keyword searches of article databases, including Compendex, Applied Science and Technology Abstracts (ASTA), National Technical Information Service (NTIS), and TRIS Online, and the World Wide Web (using Google as a search engine) were used to locate research articles, reports, industry standards, and other documents that address issues related to innovation. The relevant literature located from this activity was collected and secured for review. In addition, relevant literature was collected from printed construction industry periodicals and from other academics across the U.S. who are involved in innovation research.

The literature search resulted in a collection of journal papers, articles, reports, and other literature on the topic from a variety of resources including academic and professional journals, industry periodicals, and the Internet. The most relevant literature was found in the ASCE *Journal of Construction Engineering and Management*, ASCE *Journal of Management in Engineering*, and the *Journal of Architecture*. The literature collected was reviewed and information germane to the research project recorded.

Provided below is a summary of the relevant literature as it relates to innovation enablers, barriers, impacts, outcomes, and metrics, and other guidelines and practices for measuring and facilitating innovation on projects. It should be noted that not all of the literature on innovation that was found is described below in order to maintain brevity of the report. The reader is encouraged to review the documents listed in the annotated bibliography for additional information if desired.

2.1 Definition of Innovation

To understand and research innovation it is important to first define what is meant by "innovation". The term *innovation* is commonly used to represent something that is new and/or unique to an individual, organization, industry, or the world. Something that is new, however, may not have recognizable or significant impact, and while it may be new to one individual or organization, it may be commonplace to another. A variety of definitions of innovation with particular application to the construction industry are provided in the literature. The following are several examples:

> "Successful exploitation of an idea, where the idea is new to the unit of adoption. In construction new ideas can be in the form of products, processes, technologies, services and markets" (Egbu 2001).

> “Application of technology that is new to an organization that significantly improves the design and construction that decreases cost, schedule, and quality thereby improving business performance and the process by which new ideas turn into new components of constructed products that have economic, functional, or technological value” (Dikmen et al. 2005).
>
> “The generation, development, and implementation of ideas that are new to an organization and have practical and commercial benefits. It also involves the adoption and implementation of products, processes, technologies or services generated outside of the construction industry” (Park et al. 2004).

As part of a research study of innovation in homebuilding, Toole (1994) defines technological innovation as:

> “The application of technology that is new to an organization and that significantly improves the design and construction of a living space by:
>
> - decreasing installed cost (due to a greater volume of output resulting from a given level of input);
> - increasing installed performance (i.e., qualitatively superior output from a given level of input); and/or
> - increasing construction business performance (i.e., quantitatively or qualitatively superior process, such as reduced lead time and increased flexibility.)”

Looking beyond architecture, engineering, and construction to all industries, Dikmen et al. (2005) present a definition from the neoclassical economics view as:

> “Random events exogenous to firms as market conditions are beyond the control of individual companies.”

The term *innovation* is also distinguished from *invention*. Invention consists of a detailed design or physical manifestation that is novel when compared to the existing arts—whether the invention is actually employed in practice or not. Innovation, however, includes invention and the application of the invention. Additionally, innovation may be the application of a method that is within the realm of the existing arts but is just new to the organization adopting it.

The commonalities amongst the definitions cited in the literature are that innovation is the application or implementation of something that is new to an organization and that has significant impact. The idea can be in the form of a new product or process, and need only be new to the organization adopting it. As stated previously, Slaughter (1998) provides a succinct definition for 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.” In addition, innovation is “not a single nor an instantaneous act but a whole sequence of events that occurs over time and involves all the activities of bringing a new product, process or service to the market” (Jones and Saad 2003).

2.2 Innovation Models

Several researchers investigating innovation in the construction industry have developed models for different types of innovation and for the innovation process. Jones and Saad (2003) provide a useful summary of different models of innovation and their main contributions to the theoretical understanding of the topic. Several models are described below. The reader is referred to the summary provided by Jones and Saad to learn about additional innovation models.

Slaughter (1998) recognized that innovations fall into several categories based on the magnitude of change that occurs. These identified types of innovation are illustrated in Figure 1 and described below:

1. *Incremental*: Small changes that occur constantly and are based on current knowledge and experience (e.g., full-body safety harness like a mountain climber's).
2. *Radical*: Breakthroughs in science or technology that occur infrequently and often change the character and nature of the industry (e.g., introduction of structural steel a century ago).
3. *Modular*: Entails a significant change in concept within a single component (e.g., a new machine that ties reinforcing bars).
4. *Architectural*: Small change within a component but a major change to other components (e.g., self compacting concrete).
5. *System*: Integration of multiple independent innovations that work together to improve the facility as a whole.

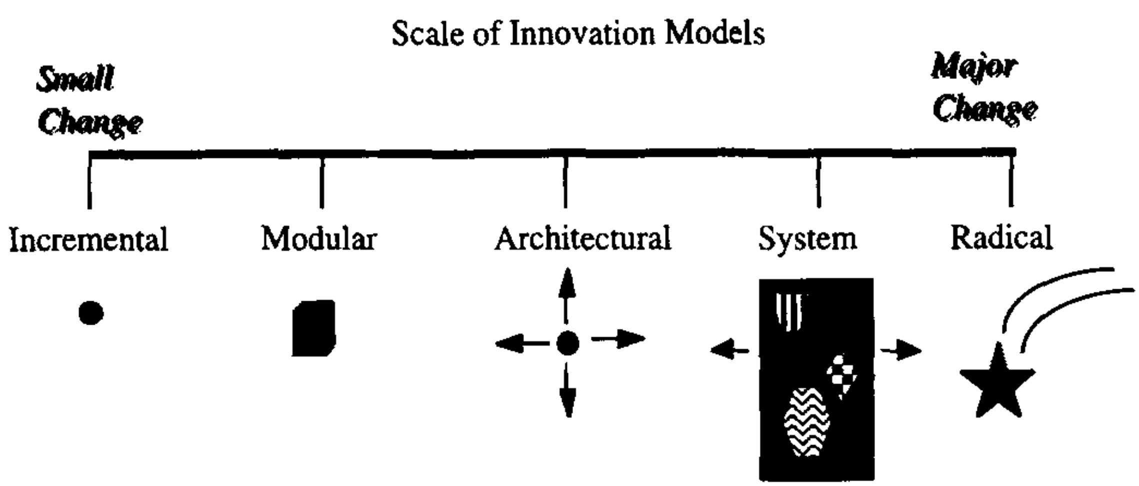


Figure 1. Innovation Models for Construction (Slaughter 1998)

The innovation process can take many forms. 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. Researchers have, however, identified practices commonly exhibited in the innovation process and have developed models that reflect the process. 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.

Based on a study of roller technologies used for asphalt paving, Abd El Halim and Haas found that the process for innovation can be systematic and provide more detail to the individual steps in the innovation process. Figure 2 shows the stages through which an innovative idea progresses and the activities that occur in each stage (Abd El Halim and Haas 2004). While the context of the process is roller technologies, the flowchart developed by Abd El Halim and Haas provides an accurate reflection of a process that leads to innovation in any context. Innovation is commonly a product of the identification of, and need to solve, a problem. The problem may be new or recurring, and requires a different approach to a solution. The process continues with traditional problem-solving activities, notably investigation of the problem and data gathering, brainstorming and development of a solution, testing of the solution, and then implementation and realization of the solution. Innovation begins when the solution is new, whether it’s a new idea generated from within the firm or acquired from outside the firm or industry. Successful implementation and outcomes of the new idea and diffusion of the innovation to other projects and firms confirm the solution as an innovation.

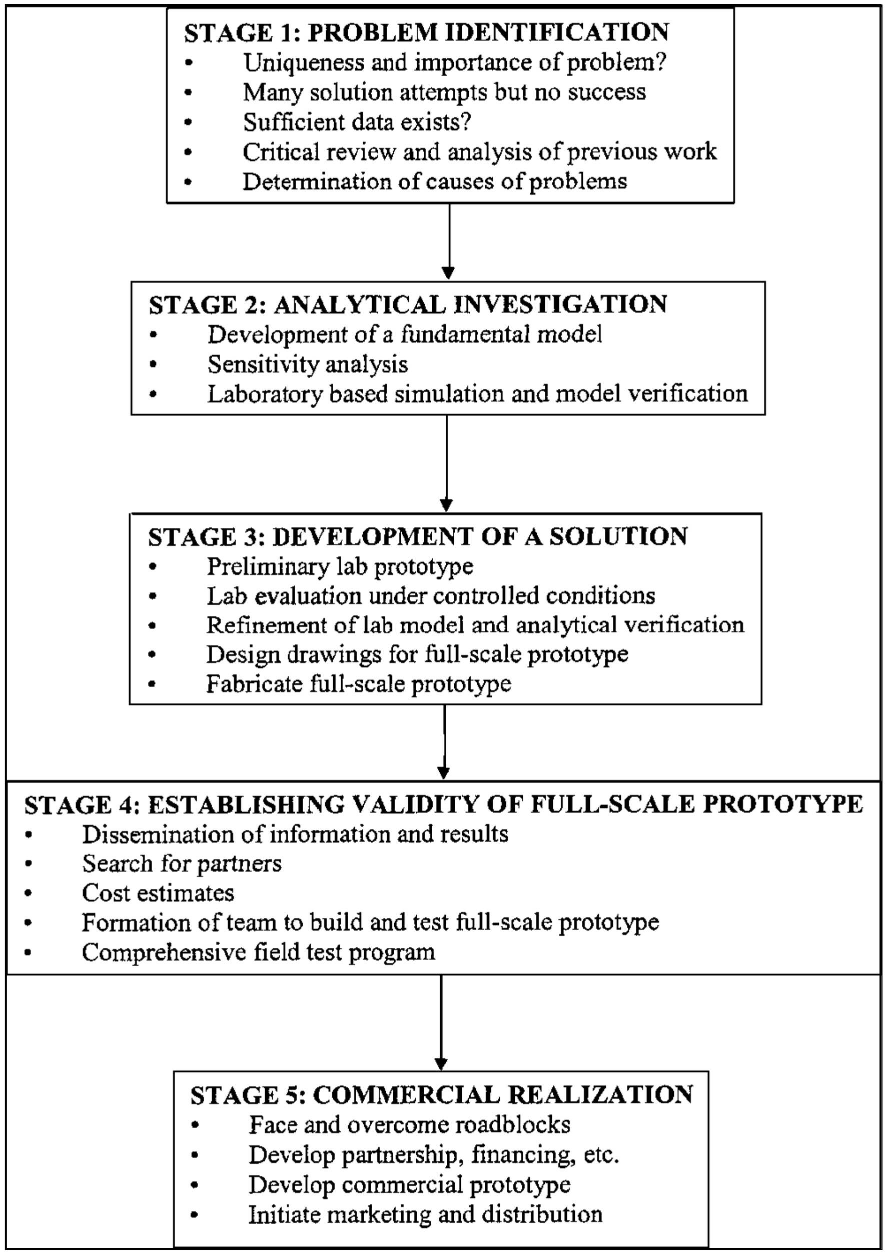


Figure 2. Major Stages in Invention/Discovery Process (Abd El Halim and Haas 2004)

Rogers (1995) takes an approach to modeling innovation through an understanding of who adopts innovations. The motivation to adopt innovations differs systematically among different groups and is normally distributed (see Figure 3). As identified in Figure 3, i*nnovators* are motivated not just by the potential of positive returns accrued through their early experimentation, but by the prestige of being the first to adopt an innovation. The next group to adopt an innovation is labeled *early adopters*. This group is more integrated in their social system than are innovators, and express a greater level of integration and a more judicious decision process to adoption. The *early majority* places high importance on peer networks and more interested in demonstrated effectiveness of an innovation before deciding to adopt it. *Late* *adopters* are those who are typically slow to adopt an innovation for a variety of reasons including marginal industry status and a tendency towards risk aversion. Lastly, *laggards* are near isolates in the social system and may only adopt innovations once legal mandates are established and enforce.

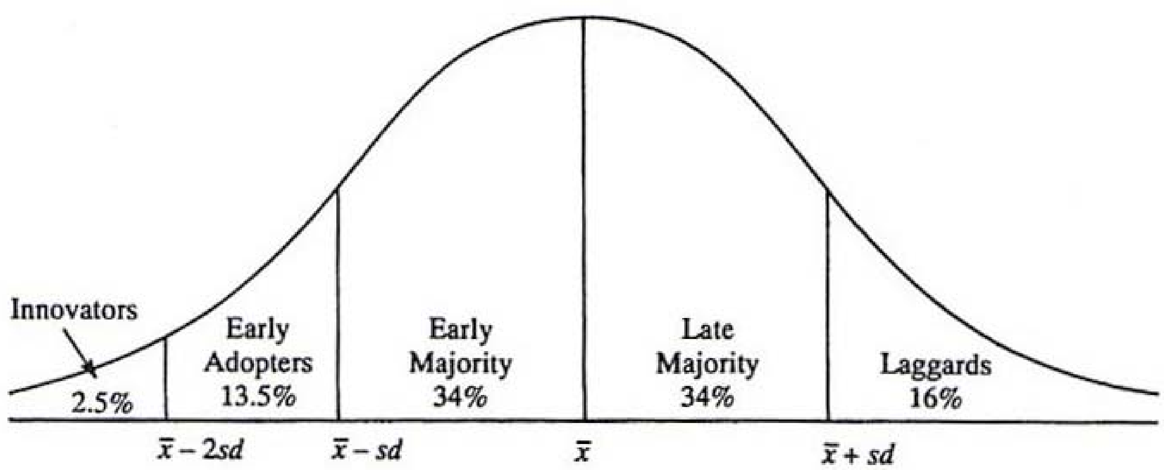


Figure 3. Adopter Categories and Distribution (Rogers 1995)

The adoption of a typical innovation over time results in an S-shaped diffusion curve when the cumulative adoption is plotted (see Figure 4). Initially, only a relatively small number of individuals or organizations (*innovators*) adopt an innovation. As a result, information about the innovation accumulates slowly until a critical mass of information is reached, allowing for the rapid take-off of the innovation. In time, the industry becomes saturated with the innovation and adoption begins to tail off.

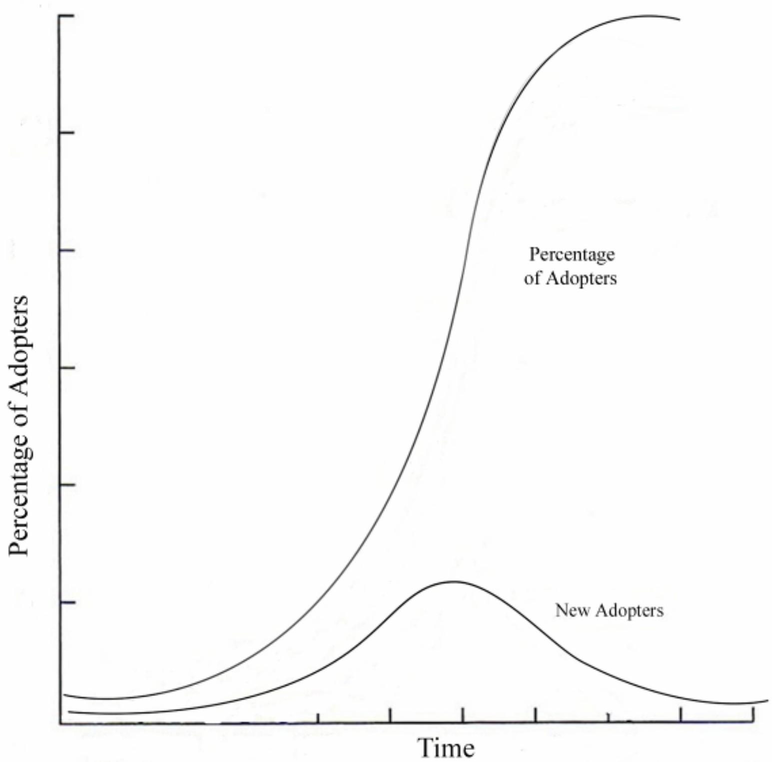


Figure 4. Cumulative Adoption of Innovations over Time (Ryan and Gross 1943, and Rogers 1995)

Much of the foundation for innovation within an organization has been linked to the management and structure of the organization. The operations of a company, as expressed in both identifiable and explicit actions and through less factual environmental and social characteristics, impact how innovation is perceived and integrated into an organization. One model that attempts to describe how a firm can be organized to affect successful outcomes, for example, is the McKinsey 7-S framework model (Waterman et al. 1980). The McKinsey 7-S model is based on the premise that an organization consists of seven "hard" and "soft" elements. The hard elements, or "hard S's", are: strategy, structure, and systems. The soft elements, or "soft S's", are: style/culture, staff, skills, and shared values/subordinate goals. The hard elements are factual and easy to identify. They can be found in strategy statements, corporate plans, organization charts, and other documents. The soft elements are difficult to describe since they are continuously developing and changing. They are highly determined by the people at work in the organization.

2.3 Motivation for Innovation

It is recognized in the literature that the conceptualization, development, and implementation of a new product, method, or system require that there be a motivation to drive the process. Lacking motivating factors, there is no incentive to innovate or change. In many cases, project-level innovation is initiated when solutions are needed to solve problems or enhance project performance. This occurs when projects are “in a pinch” or when improvement is needed to meet project objectives (Park et al. 2004).

However, innovation throughout an organization or an industry requires other motivators besides just solving a particular project problem. When considering the drivers of innovation one must consider what the firm is trying to do in its overall strategy and whether the technology strategy is intended to help the firm with its internal cost structure, or to help the firm to compete in the open market against competitors (Macomber 2002). Innovation can be spurred by other industries and the environment that surrounds the construction industry (Arditi et al. 1997). For example, equipment manufacturers can drive innovation. They act as a catalyst by being inventive, improving efficiency, and allowing workers to perform more versatile tasks (Arditi et al. 1997). Construction is being radically changed by new technologies and innovation must take place in order to keep up (Slaughter 1993).

Innovation is also motivated by competition. It is commonly felt that in order to survive in an open market, firms must innovate. Foreign competitors are already innovating and organizations need to continuously adapt to complex and changing conditions. Innovation allows a firm to effectively compete (Steel 2001; Tatum 1986a).

Motivators internal to an organization typically include: increased profit, penetration into a new market, being recognized as a leader, and achieving a level of political or economic status (Egbu 2001). Reputation for innovation makes a firm attractive to clients and allows for further opportunity for innovation (Kangari and Miyatake 1997). Macomber (2002) indicates that many technologists and observers have noted that clients/owners drive the innovation process. Owners call for better performance and many are willing to pay for the adoption of new technologies (Tatum 1991; 1986a). In addition, Macomber notes that owners likely to be interested in innovation for economic reasons will be those who have a high volume of projects (either in size or in quantity) and who can quantify “time to revenue” and hence quantify the cost benefits of acceleration gained by innovation (Macomber 2002).

A recent study of innovation in homebuilding exposed differences between those firms that are motivated and leaders in innovation and firms tend to wait for change to occur (Koebel et al. 2004). The results of the study indicate that more innovative firms are more likely to:

- Have a technology advocate within the firm;
- Stress the importance of being creative and the first to use new products;
- Use technology transfer programs; and
- Use union labor at least sometimes.

On the other hand, firms that were viewed as later innovation adopters are more likely to:

- Emphasize marketability and profit;
- Associate the firm’s success with land development; and
- Emphasize the “tried and true” and the risks of new materials and products.

The study also found that builders tend to follow the lead of the homebuyer (owner). Homebuyers are viewed as being risk-averse and resistant to new products. As a result, the builders have no choice other than to avoid innovation. Koebel et al. found that "Builders are less likely to be innovative if they emphasize that their customers prefer the 'tried and true' and don't like nontraditional products or features…". Conversely, those builders who were found to be more innovative, proactively communicate with their clients to educate them about new technologies (Koebel et al. 2004).

2.4 Enablers of Innovation

Characteristics or elements within an organization or on a project that enable innovation to occur, or to occur at a faster rate, can be found in the literature. The following are enablers of innovation in the construction industry that are commonly identified in the literature (Tatum 1986a; 1986b; 1991; Slaughter 1993; 1998; Ahmad 1991; Kangari and Miyatake 1997; Bossink 2004):

- Contractor input during the design phase.
- Overlap of the different project development phases.
- Design-Build project delivery method.
- An organizational culture that supports innovation as a method of winning construction projects.
- An organizational innovation "champion" and entrepreneur, including a technical innovator, business innovator, product champion, and chief executive.
- Computers, management techniques, robotics, and new materials being developed at incredibly fast rates.
- Multiple firms working together in a collaborative environment.
- A positive social and political context of a project.
- Attention to user needs and marketing.
- In-depth understanding of customers and markets.
- Commitment of major participants (owner, designer, contractor) to innovation.
- Product uniqueness, marketing knowledge, and technical and production synergy.
- Design of the product and process within the control of one firm, as in the Design-Build delivery method.
- Strategic alliances that investigate and promote relevant technological inventions from other industries to be applied to construction.
- Effective information gathering.

The importance of an integrated project team to innovation on a project is clearly identified in the literature and cannot be understated. Contractor input during the design phase, overlap of the different project development phases, and the design-build project delivery method are all enablers of innovation as listed above. These practices foster the communication of ideas across traditional lines of separation, and enable different ways of approaching problems, data sharing, and learning to occur. Putting these into practice requires participation and support from the project owner. Some owners, for example, have recognized the "development of tools that combine design, communications and database capabilities and are quick to grasp their potential not just in tweaking design, but in changing the entire construction process to make it more efficient" (ENR 2006). This recognition has led to the creation of a national strategy group composed of owners, contractors, and architects to "examine the practical aspects of implementing a project or program delivery process that brings in contractors and designers early and facilitates communication between them" (ENR 2006).

Successful innovation has been investigated in the context of the presence of situational factors that facilitate idea generation, development, and implementation. Bossink (2004) identified the following four situational factors that impact innovation:

- *Environmental Pressure*: Influences that force and stimulate organizations to innovate. The market typically exerts this pressure (e.g., equipment innovation was a response to market pressure). Guaranteeing markets for innovative firms has helped to spur innovation in the U.K.
- *Technological Capability*: Technological capabilities of organizations in the industry push the implementation of new solutions. Industry evaluation of invention can ensure quality of innovation during implementation.
- *Knowledge Exchange*: Academic importance is stressed. Participation in academic studies performed by universities, research institutes, and knowledge-intensive business solutions leads to creation and adds objective support for implementation.
- *Boundary Spanning*: Integration of the design and construction disciplines is an important driver for innovation. It prevents innovative designs that cannot be constructed.

The four factors identified by Bossink are significant to the present research study. As discussed below, innovation enablers are often cited as being related to the surrounding environment, resources, and communication within a firm. The integration of diverse disciplines within a project team, especially design and construction, is another key to innovation that is frequently cited. These impacting factors can enhance innovation when appropriately fashioned and be detrimental to the innovative process when they create roadblocks and discouraging climates. They act as leading indicators for measuring the success that a company might have at innovation.

The situational factors put forth by Bossink closely relate to another enabler of innovation that is frequently cited which is organizational culture. Cultures are patterns of interacting elements, and represents the accumulated learning of a group – the ways of thinking, feeling, and perceiving the world that have made the group successful (Schein 1999). Culture includes the shared beliefs in the minds of all employees. "There is growing recognition that fostering a culture of innovation is critical to success, as important as mapping out competitive strategies or maintaining good margins" (Kelley 2005). While establishing a culture that promotes creativity, acceptance of new ideas, and a drive to always improve is essential to the innovation process, measuring an organization's culture is difficult. Approaches to measuring organizational culture have been developed although there is no consensus as to the correct approach (for example, see Cameron and Quinn 1999; Hofstede and Hofstede 2005; Schein 1999).

The impact of specific participants on a project or in an organization has been researched as well. Park et al. (2004) developed a model based on the dynamics of construction which incorporates the influence of several individual and situational factors that impact implementation of new products and processes. Two main elements were found to impact the implementation component of innovation: championing behavior of management, and motivation of team members facilitated by a supportive organizational climate. The researchers found that project complexity, size of project, size of project team, and resources are impacting situational factors. The innovation champion's behavior was another factor identified. Observable behavior that is directed toward seeking, stimulating, supporting, carrying, and promoting innovation is important to success. In addition, a supportive organizational climate, consisting of two elements – resource supply and support for innovation – are crucial to enabling innovation.

Toole (2001) argues that the success of an innovation depends on the ability of the innovators to show that the innovation will:

- *Reduce Cost*. Innovations that allow a contractor to lower the cost of performing a portion of the project will allow the contractor to either maintain its price and increase profit margins, or lower its price and increase market share.
- *Decrease Schedule*. An innovation that does not necessarily reduce the average cost of a task but reduces its variability is desirable from a risk management perspective.
- *Enhance Performance*. Performance refers to all physical characteristics of a building product and can be divided into three sets: construction performance, installed performance, and design performance. Construction performance refers to the characteristics of a product relevant to the construction process. For example, products that can be constructed with less skilled labor and products that can be stored on-site or left exposed without suffering weather damage are highly desirable.

It is clear from the research of Toole and others that just having a good idea is not enough in the construction business to cause the innovative change. An understanding and demonstration of the financial benefits resulting from the innovation are required to affect the innovation process. Return on investment to stakeholders is a significant concern that drives the decision to make the change happen. In the absence of external regulations or other controlling factors, the lack of a positive return on investment will typically stall the implementation of a new idea.

The management of knowledge has been shown to be a key aspect of innovation as well. The ability to develop new ideas and identify the risks and rewards commonly resides within the experiential knowledge and expertise of a firm. Much of this knowledge is tacit, embedded in the culture of a firm. Train and Egbu (2006) reveal that successfully accessing this often tacit knowledge through effective knowledge management increases a firm's ability to innovate. The research indicates that as knowledge moves from the explicit through to the tacit, the innovative capacity of an organization will increase.

It should be noted, however, that success in innovation is rarely associated with doing one or two things outstandingly well (Jones and Saad 2003). Rather, it is dependent on performing all functions competently and in a well-balanced integrated manner, taking into account the specificities of internal and external environment.

2.5 Barriers to Innovation

There are many barriers to innovation that are identified in the literature. The barriers exist at the project, organization, and industry levels. Researchers have identified the following barriers to innovation in the construction industry (Mohamed and AbouRizk 2005; Ahmad 1991; Christensen 1997; Slaughter 1993; 1998; Egbu 2001):

Project level barriers:

- Large scale of components/facility
- Lack of space available
- Extensive transportation requirements or inadequate transportation facilities
- Inability for full-scale testing
- Complex facilities
- Interrelationship of systems in a facility (innovation in one system may affect others)
- Longevity of use of an innovation (hard to predict lifecycles)
- Temporary alliance of independent organizations
- Challenging suppliers for different projects
- Social and political context of constructed facilities:
  - Codes/standards
  - Public input
  - Safety/environmental inputs
  - Regulatory inspections
- Liability is borne more by individual designers, workers, or supervisors
  - Compared to the manufacturing industry where it is borne by the company or by the industry sector.
- Poorly timed commitment to use the innovation (e.g., too early or too late)
- High degree of implicit or explicit coordination among project team members
- Requirement for special resources: availability, expense, quality
- Nature and type of supervisory activities and competency of supervisors

Organizational level barriers:

- Core competencies can turn into core rigidities
- Inability to link innovation strategy to the wider business strategy
- Managing organizational risks
- Ability to scan environments to pick up and process signals about potential innovation
- Lack of resources
- Lack of buy-in from upper management and investors
- Market acceptance
- Regulations
- Lack of metrics
- Maintaining an innovative advantage over competition (quick diffusion)
- Creating a business environment that motivates and adopts innovation
- Managing the technical knowledge and expertise required to generate innovative solutions in a structured and systematic way without reinventing the wheel.

- New technologies can cause a firm to fail if they stifle the firm's ability to maintain a sustainable short-term income.

Industry level barriers:
- Innovation within an industry sector but not across sectors
- Government regulations
- Competitive bidding provides little margin for a contractor to implement new techniques or upgrade quality in its product.
- The market itself is a barrier because it is extensive, unstable, fragmented and geographically dispersed. This creates an uncertain environment for innovation, thereby increasing risk dramatically.
- Construction firms rarely have the capital to invest in risky innovations.
- Construction is closely regulated by building codes which are nationally, state-wide, and locally enforced.
- Transient nature of construction makes innovation requirements and benefits different from one location to the next.
- The changing ratio between construction costs and financing costs.
- Incentives for innovation are low.

While barriers to innovation in the construction industry have been identified, previous research does not provide a ranking or rating of the barriers in terms of their magnitude and/or frequency of exposure. The frequency with which barriers are noted in literature may give an indication of it's magnitude. For example, fear of change, the competitive bidding process, selected project delivery method, and industry codes and regulations are often cited in the literature as barriers. It could be assumed then that these are the most significant barriers. The results of the present research as described below provide quantitative evidence as to the magnitude and frequency of the barriers.

The need for research and development (R&D) to occur and to have R&D capabilities also presents a barrier to innovation. Firms have a hard time innovating unless they are deeply rooted in R&D (Dulaimi 1995). While firms in other industries such as the semiconductor and medical industries are intimately involved in generating and developing new technologies, most construction firms are not. As a result, 60-80% of new construction technologies developed in the U.K., for example, fail (Dulaimi 1995). More investment is needed in R&D in the construction industry.

Failure of a new technology to gain widespread implementation may result because of conflicts in the development and diffusion of technologies. Christensen (1997) presents four laws of disruptive technology to an industry, whether it be the construction industry or another work industry. These four laws are:

1. Companies depend on customers and investors for resources.
2. Small markets do not solve growth needs of large companies.
3. Markets that do not exist cannot be analyzed.
4. Technology supply may not equal market demand.

Christensen's statement of disruptive factors is important to understanding innovation and the innovation process in the construction industry. Design and construction problems are often solved using unique ideas on projects. However systematic innovation occurs when the solution is transferred to other projects and to other firms throughout the industry. This diffusion can be hampered or blocked with the presence of the disruptive factors. Minimizing or eliminating the factors that disrupt diffusion is needed in order to ensure that innovation occurs in a firm and in the construction industry. Christensen and Raynor provide guidance on how a company can resolve the challenges of creating positive change within their business enterprises (Christensen and Raynor 2003).

2.6 Benefits and Outcomes of Innovation

The outcomes of successful innovation can be beneficial to a project, organization, and even the construction industry. When an innovation is successful, the following benefits have been identified (Madewell 1986; Slaughter 1998):

- Increased efficiency/productivity
- Cost savings
- Increased economic growth
- An increase in market growth through the introduction of new products and reduction in costs.
- Social benefits
- Increased technical feasibility of projects
- Appearance of new markets
- Improvements in quality of life (innovations for residential structures)
- More accessible facilities (general industry)
- Advance current technology and insert new technologies from other industries into construction
- Intangible benefits:
    - Improved reputation
    - Ease of work
    - Attraction of promising new hires

It is recognized as well that innovation leads to a competitive advantage (Madewell 1986). Innovation allows contractors and construction managers the opportunity to obtain contracts and maintain work (Macomber 2002). It is cautioned, however, that the cost savings are often passed on to the owner and not realized by the contractor. That is, when a contractor finds an innovative way to perform its work, for example, the owner often receives the financial benefits as a result of lower construction costs. Mechanisms may not be in place to share the cost savings. As a result, an immediate benefit to the contractor may not be realized. Lacking an immediate and recognizable financial benefit, motivation to innovate is diminished. The result is that no change occurs. Firms have little incentive to change if there is no tangible return on the investment. This disconnection is one reason why innovation in the construction industry is slow. Overcoming this disconnect requires greater collaboration between the owner and builder. This can be accomplished through value engineering efforts, performance bonuses, project team integration, risk sharing, and other contracting strategies. Further discussion of suggested practices to equitably share the benefits of innovation is provided in the Analysis and Discussion section below.

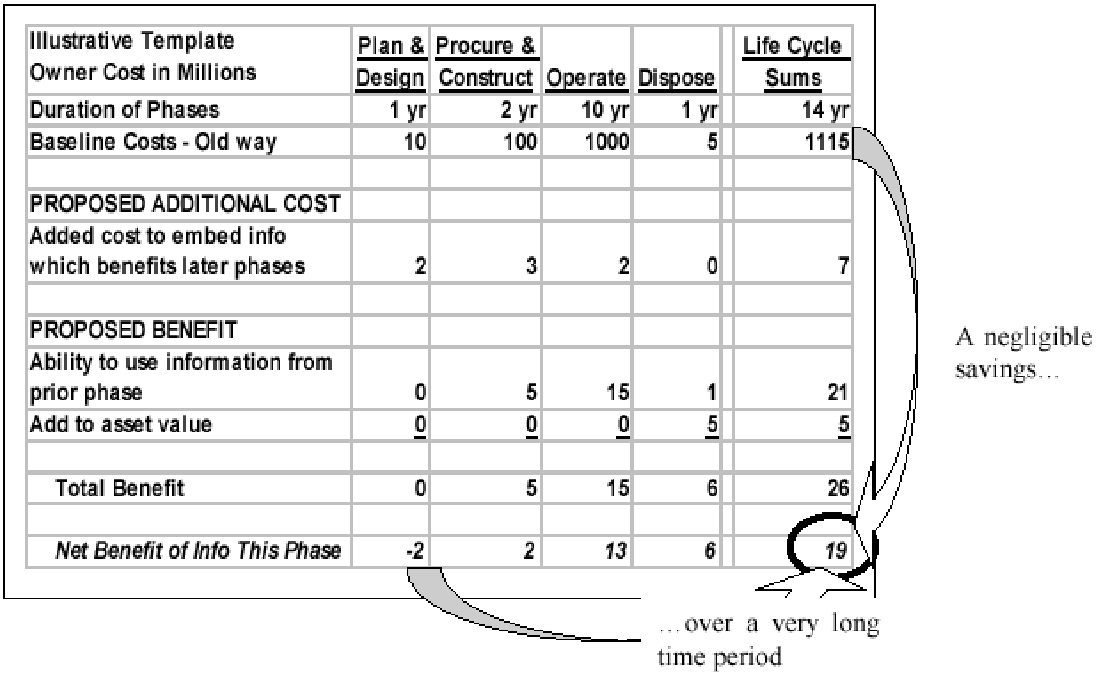
When firms realize and gain the benefits of innovation, the payback is measurable. In his article titled, "Creativity Pays. Here's How Much.", Henry (2006) compares the profit margin growth of the Top 25 Most Innovative Companies in the world to other companies. Henry points out that "The innovators achieved median profit margin growth of 3.4% a year since 1995, compared with 0.4% for the median Standard & Poor's Global 1200 company."

As with the barriers to innovation, no ranking or rating of the benefits was found in the literature. Evidence of the magnitude of the benefits is found in the findings of the current research study as described below.

2.7 Innovation Metrics and Assessment

Assessing the potential of an innovation and measuring its success play a significant role in energizing innovation in an organization. Questions commonly arise as to the success of an innovation that has been implemented. Are the innovators adding value to the project and the organization reaping the benefits of their innovation? Effective strategic planning and management related to an innovation require knowledge of the potential and actual impacts, both positive and negative. This process requires metrics which reflect the impact of innovations. Measurement of the metrics on a project, in an organization, or with respect to a specific innovation can allow strategic planners and managers to objectively assess the success of an innovation.

Existing literature identifies means for assessing innovation and appropriate metrics for the assessment process. Figure 5 below, for example, illustrates a process for evaluating the lifecycle cost/benefit of an innovation (Macomber 2002). In most circumstances, savings from lifecycle information costs are negligible in the context of the entity's total cost picture over time. In this template, the components of design and construction are captured in the four major phases of the project: design, construction, operations, and disposition. The baseline costs to design the building, build it, operate it (including payroll and materials input and output) and then to dispose of it are postulated. The balance of the table shows the flow of putative lifecycle costs and benefits. In the example shown, the designer spends an additional $2 million to embed information. The contractor and operations teams benefit down the line (in this case, the construction cost is reduced by $5 million due to the use of added information embedded during the design phase). But the *designer* doesn't benefit. So a question arises as to why the designer should spend the money? Secondarily, even if the owner reimburses the designer so that the contractor can invest in capturing lifecycle information that benefits others down the line; it's still a very small benefit over a very long period of time, in relation to the owner's total cost picture (Macomber 2002).



Illustrative Template Owner Cost in Millions	Plan & Design	Procure & Construct	Operate	Dispose	Life Cycle Sums
Duration of Phases	1 yr	2 yr	10 yr	1 yr	14 yr
Baseline Costs - Old way	10	100	1000	5	1115
PROPOSED ADDITIONAL COST					
Added cost to embed info which benefits later phases	2	3	2	0	7
PROPOSED BENEFIT					
Ability to use information from prior phase	0	5	15	1	21
Add to asset value	0	0	0	5	5
Total Benefit	0	5	15	6	26
Net Benefit of Info This Phase	*-2*	*2*	*13*	*6*	*19*

Figure 5. Life Cycle Cost Savings Template (Macomber 2002).

Based on a study of construction innovation in Japan, Kangari and Miyatake (1997) present a flowchart that Japanese organizations use to evaluate which innovations will have the greatest impact on business performance. The following questions are asked when evaluating the possibility of implementing an innovation:

- Do the group members have the required expertise?
- Do they have the necessary time to carry out the technology development?
- Do they exhibit the necessary motivation and interest in the development project?
- How technically achievable is the development project?
- Does the technology development project still satisfactorily complement the current technical corporate strategy?
- How does this new technology compare with the technology of the company's competitors?
- If competitors possess similar construction technology, how well does the proposed technology allow for technical differentiation?
- In light of what was learned in the feasibility study, is there any reason for discontinuing the new technology development?

If a technological proposal is considered satisfactory based on the above questions, the organization's management will consider the following questions:

- How well does the new technology meet the firm's strategic technical goal?
- How well does the new technology fit in with such goals as new marketing in core business, strengthening of core business, licensing of technology, finding new areas for manufacturing, and enhancing the firm's image as a technology leader?
- How well does the new technology relate to current technologies?
- How innovative is the new technology?
- What is the current market size of existing or similar technology?
- What will the growth of the market be over the next five years?
- What are the group's abilities based on past performance?
- How clear is the proposed new technology development process?

In addition to measures to assess the potential for an innovation to be successful, possible metrics for assessing the outcome of an innovation are identified in the literature. The following metrics for assessing the success and impacts of innovation in the construction industry have been suggested (Egbu 2001; Turrell 2006; Tucker 2004):

- 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
- Time to market
- The level of client satisfaction
- The average failure rate
- Linkage of innovation planning to overall business strategy
- The extent to which the workforce is involved with innovation
- Revenue growth of new products
- Patent submissions
- Idea and submission flow through and organization
- Percent of current year sales due to new products released in the past N-years

Dikmen et al. (2005) identify leading indicators and trailing indicators of innovation. The leading indicators include: objectives of the firm, required and available resources, and government incentives. Trailing indicators include: technological advancements, improvements in schedule, budget, and quality, client satisfaction, monetary gains, social benefits, and increased effectiveness of the firm.

The Construction Industry Institute (CII) and National Science Foundation (NSF) identified five factors that need to be present in order for change (innovation) to occur in engineering and construction through the implementation of new technologies and transfer of information (CII/NSF 1997). These five factors are:

1. Change must have value to the owner. Most changes happen when demanded by the project owner. The owner, who allocates and controls funding, must see financial value in any change.

2. It’s proven that change works. This demand is the first defense against change. The fact that research mostly happens in a controlled environment while the implementation occurs on the jobsite easily leads to questioning the applicability of new practices or technologies.
3. An innovation-oriented culture exists. Where to find the information and how to disseminate it is a major challenge. To impart credibility, an innovation-oriented culture needs the support of a high level person as a champion and a formal information collection and dissemination system.
4. An innovation champion must be present. For changes to happen in most organizations or companies, a champion has to be designated. This champion is responsible for implementing a change or innovation. A strong driver of change is the competition with peer companies and the competitive advantages derived from an innovation. Probably the most powerful change-agent is a “crisis”. When a crisis appears, the drive, the threat, and motive are in place to improve technologies and change inefficient practices.
5. Lessons-learned feedback is valued and used. There must be continuous feedback and activation of innovations. The creation of permanent facilities involves a series of processes including planning, design, procurement, construction, maintenance, and operations. Often neglected is the aspect of improving the next undertaking by applying the experience and lessons learned from the just-completed job.

2.8 Summary

Innovation is commonly recognized as consisting of both invention and application of new ideas. Innovations in the construction industry can take many forms, including new products, processes, services, and systems, and be initiated from either within or outside a project or organization. To be considered an innovation, it is typically felt that the new product or process must create some non-trivial change or impact to a project, organization, or the industry. In addition, the change must occur not only on one project (i.e., problem solving to “get the project built”) but be diffused throughout a company and the industry.

Existing literature has identified numerous motivators, enablers, barriers, and benefits of innovation. Increasing productivity, reducing cost, staying competitive, and being recognized as a leader are common motivators for innovation. At the project level, simply solving problems in order to build a project and bring it in on time and within budget is also a motivating factor. These motivating factors are similarly recognized as benefits of innovation. On the other hand, barriers to innovation can, and do, exist at the project, organization, and industry levels.

Successful innovation occurs with the generation of new ideas and the opportunity to test, develop, and implement those ideas. As a result, the factors that enable innovation are those that promote the generation of ideas and facilitate exploring those ideas. Examples of enablers of construction innovation include: the overlap of design and construction; multiple firms working together in a collaborative environment; open communication; and effective information gathering. These and other factors are a reflection of the structure of an organization and its culture with respect to innovation. An organizational structure that allows and promotes the brainstorming and acceptance of new ideas and the testing of those ideas enables the innovation process to occur. Additionally, a culture of curiosity and openness to new ideas can also promote innovation. When these factors are absent, innovation is hindered.

3.0 RESEARCH METHODS

This section of the report describes the research methods employed to meet the stated study objectives. Three primary research efforts were conducted: a survey and interviews of the construction industry to benchmark innovation in the industry; a survey of innovative product developers and manufacturers; and case studies of construction projects. Each of these efforts is described in detail below along with the reasoning for their selection and the environment under which the research was conducted. Validation efforts, also described below, were conducted to confirm the conclusions drawn from the three primary research activities.

An initial task as part of the research was to establish a definition of innovation to be used in the study. For this task, the definitions stated in literature were considered along with the goals and objectives of the study. For the purpose of the study, the following definition of innovation was adopted based on that provided by Slaughter (1998):

> "Innovation is 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".

Under this definition, innovation includes both the generation of a new product, process, or system, and its implementation. Additionally, 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. That is, the innovation must be used on subsequent projects within a firm or by other firms within the industry. 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".

3.1 Methods and Environment

As stated previously, the research study is aimed at investigating how innovation can be enhanced and measured in the construction industry and at providing resources to the industry to support it's innovation efforts. Given the fragmented and dispersed nature of the construction industry, and the difficulties associated with controlling for confounding factors on construction projects, an experimental approach is very difficult and time-consuming to implement. Cause and effect must be assessed via other research methods. Information about the factors to be considered as part of this study exists within the culture and structure of an organization and project and the tacit knowledge of industry professionals. As a result, extracting data related to these factors requires communication with and involvement of the construction industry.

To account for the difficulties and constraints associated with conducting construction research and the nature of the research topic, the research methods implemented in the study incorporate a multi-faceted approach consisting of surveys, interviews, and case studies. These methods were selected due to the open nature of the information to be gathered, the diversity of the study population, and to ensure reliability of information gathered. On-line surveys allow for gaining specific project information from a widely dispersed and diverse sample. In-person interviews provide the opportunity to collect in-depth information that cannot be practically gained through on-line surveys. The case study method allows for unstructured interview questions, designed to most fully expose potential innovative techniques and allow the researchers to probe further when needed. Using multiple research efforts enables analyzing the research questions from different perspectives rather than relying on just one set of data. The benefits of this approach include increased confidence in the study findings. This is especially useful for studies in which confounding factors make it difficult to pinpoint cause and effect, and when the sample size is small relative to the population to make generalization of the findings suspect. That is, while the sample size may be small for each individual research effort, when the combined results of all of the independent efforts point to the same findings, the level of confidence in the results is high.

The research environment under which the study was conducted consists of projects and organizations within the U.S. construction industry, and projects that have been completed within the last five years. Projects of different sizes and types, including buildings, heavy civil, and industrial projects, and which are distributed geographically throughout the U.S., are included to balance the distribution of projects and reflect the breadth of the construction industry. All aspects of integrated project delivery, including design, construction, and project management, are included. In addition, the study includes the consideration of projects based on the composition of the integrated project delivery team, i.e., fully integrated vs. joint venture.

3.2 Benchmarking Survey and Interviews

As stated previously in this report, while there is a perception that the construction industry is not innovative, innovation does occur and there are many examples of innovation. It is perhaps the case, however, that the rate of innovation in the construction industry is different than that perceived in other industries such as the electronics, medical, and chemical industries. While other industries have generated new products and processes at what seems to be a fast rate, innovation in the construction industry may occur at a lower rate. The second task in the research project involved investigating the current level and extent of innovation in the construction industry. Understanding general industry practice provides the opportunity to expose innovative projects and technologies and better understand how they came about and can be facilitated.

To assess the current level and extent of innovation, the second task in the research involved conducting interviews of construction industry personnel. Interviews provide an opportunity to gather objective project and organizational data, gain perspective on subjective variables, explore specific issues to a great depth, and record anecdotal support for data that is difficult to acquire through other means. The interviews also allow the researchers to generate interest amongst the interviewees to provide more detailed information as part of the follow-on case study effort.

The time, cost, and transportation requirements of conducting interviews, however, limit the number of interviews that can be conducted. Therefore, to broaden the study sample, an on-line survey was added to the study. On-line surveys allow for the collection of data over a wide population and for the accumulation of more responses than is feasible using just interviews.

Using the results of the literature review, a questionnaire was developed for use in the on-line survey. In addition to asking for personal and organizational demographic information, the questionnaire solicited information about the types of innovations that occur, the rate of innovation, organizational features that support innovation, metrics used to assess innovation, and personal beliefs about the organization's ability to innovate and performance with respect to innovation. The set of questions was developed and used as a data collection instrument to maintain consistency in the data collection process and ensure that the desired data is collected. Several open-ended, exploratory questions were added to the questionnaire for use only in the interviews to gain in-depth information about specific innovations and the innovation that occurs in the organization. The questionnaire and the cover letter used for its distribution are provided in Appendix 9.1 to this report.

Following the development of the questionnaire, a list of construction industry personnel to survey was created. The list was compiled using outreach contact lists of the OSU Construction Engineering Management Program and personal contact lists of the researchers. The personnel on the list work in architecture, engineering, and construction firms located throughout the West Coast. From this list, a small sample was selected for interviews. Selection for interview was made based on the type of firm/discipline in order to get a good cross-section of the industry, e.g., small and large firms, general contractors and subcontractors, architects and engineers, and various design disciplines. Consideration was also given to their proximity relative to Oregon State University in order to fit within travel limitations.

A total of 27 people were selected for interview (8 A/E's, 9 GC's, 3 sub's, 1 supplier, 3 owners/developers, and 3 other). Those selected for interview were contacted to ask for their participation in the study. From this effort, a total of ten interviews were conducted.

The questionnaire was also placed on-line and e-mails were sent out to the other people on the contact list asking that they complete the survey on-line. A total of 272 e-mails were sent out, of which 75 were returned as undeliverable, leaving 197 people contacted regarding the on-line survey. In addition, the Associated General Contractors (AGC) Oregon-Columbia Chapter and the national office of the Design-Build Institute of America (DBIA) distributed e-mails to their membership asking that they complete the survey. The e-mail went out to 1,073 AGC Oregon-Columbia Chapter members, and approximately 2,700 DBIA members.

3.3 Innovative Products Survey

To investigate innovation at the product development level, the benchmarking survey was followed by a survey of firms which have developed innovative products. In the development of their products, these firms have progressed through the innovation process from the initial conception of a new idea through research, development, and marketing of the new product to the industry. The lessons learned from these companies, and barriers and benefits realized, as a result of their efforts can be used as a model to understand and affect innovation on construction projects. The innovative products survey was added to the research scope of work following the results and analysis of the initial benchmarking survey.

This task began with the creation of a list of newly developed innovations in the construction industry. Two sources were used to create this list. The first source was the Construction Innovation Forum's NOVA Award website (http://www.cif.org/). 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. CIF regularly recognizes innovations in the construction industry with its NOVA Award to honor innovations that have proven to improve construction quality and cost. The website lists those technologies that were nominated for the award and which received the award, along with descriptions of the innovations and contact information. The innovations list on the website for innovations listed within the past 5 years was downloaded along with corresponding contact information.

The second source of innovations was the Emerging Construction Technologies (ECT) website sponsored by Purdue University and the Construction Industry Institute (http://www.new-technologies.org/ECT/Index.html). This website describes promising construction industry technologies related to a variety of materials, processes, and systems. The technologies listed on this website were also downloaded along with the corresponding contact information.

A total of 233 innovative products were identified from the two websites, for which e-mail addresses of 189 of the products were identified. A questionnaire similar to that used for the benchmarking survey was developed for distribution to the product manufacturers. The questionnaire along with the cover letter is provided in Appendix 9.2. The questionnaire was e-mailed to the 189 firms. A list of the 233 products collected from both websites is shown in Appendix 9.3.

3.4 Project Case Studies

The third research effort consisted of conducting case study reviews of construction projects to understand what factors affect innovation on a project and how innovation can be measured. In order to understand the factors that distinguish innovative projects, a study sample was created which consisted of two types of projects: award-winning and "regular" projects. It was conjectured that award-winning projects were different than 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 impacted 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 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 impact 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 ability to distinguish innovative projects from other projects is a key aspect in the research study.

The list of award-winning projects was created from a variety of sources. Various regional and national owner, designer, and constructor organizations and publications (i.e., DBIA, AGC, ASCE, ENR, and other construction industry publications) regularly give out awards for projects that stand out in their design and construction. The websites of these sources were searched for projects that have received awards in the past 5 years, from which a list of 20 award-winning projects was created. The 20 projects were selected from the following sources: ASCE OPAL award; DBIA national design-build award; Greatbuildings.com; Oregon.gov Great Buildings of the Year; Buildings.com; CIF NOVA award; and AIA.

The list of regular projects was created using Engineering News-Record (ENR). ENR regularly posts advertisements for projects that are out for bid. Projects of all different types, sizes, and locations are advertised. Issues of ENR from the past 5 years were reviewed and a list was created of the projects advertised. Using this initial list, 20 projects were randomly selected.

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. Information about the 20 case study projects, including contact information, was collected via the websites described above and other websites located through on-line searches. A list of the 20 case study projects is provided in Appendix 9.4.

To assist with the interviews, an interview template with specific questions was created (see Appendix 9.5). The questions asked for information about: the demographics of the respondent (title, years of experience, etc.); organizational characteristics (e.g., upper management support, communication, and recognition and rewards); project level practices (e.g., delivery method, competition, and extent of collaboration across disciplines); 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 their answers and go into more depth about the projects.

Personnel involved in the projects were contacted for interviews about the projects. Each contact person was sent the interview template to review the questions before the interview. A day and time were scheduled for the interview and the interviews conducted over the phone and in-person. The responses to the interviews were recorded in a spreadsheet for analysis.

3.5 Industry Input and Validation

The survey, interview, and case study efforts described above provided project and innovation data for the study. Analyses of the data were conducted to identify guidelines and suggested practices for enhancing and measuring innovation. These results and analyses are described in the following sections of this report. In addition, the study included several activities to validate the findings. The goal of the validation efforts was to provide a “second opinion” about the study findings based on industry knowledge and opinion, to identify whether anything is missing from the results which should be investigated further, and to ensure the applicability and relevance of the suggested practices.

The research findings were presented to the industry for input on three different occasions. Preliminary findings from the benchmarking survey were presented at the fall meeting of the Industry Advisory Board (IAB) for the Construction Engineering Management (CEM) Program at Oregon State University (OSU). The CEM IAB provides industry input and oversight of the

CEM undergraduate program. IAB membership consists of fifteen industry professionals representing a wide spectrum of the construction industry. Board members work for local, regional, and national firms with offices located in Oregon and Southwest Washington. The board members were asked to consider the preliminary findings and provide input based on their work experiences. Comments provided by the board members were recorded and incorporated into the study were appropriate.

The final research findings were presented to the combined industry advisory boards of the CEM Program and the Civil Engineering Program at OSU at a board meeting in June 2007. Similar to the CEM IAB, the Civil Engineering IAB is composed of 14 industry professionals who represent different facets of the civil engineering field for local, regional, and national organizations and firms with offices located throughout Oregon and Southwest Washington. Both boards were again asked to verify and provide input on the research findings during the presentation. The board members were asked to provide input and comments on the study findings based on their work experiences and knowledge of the industry.

Industry input on the final research findings was also solicited from the Advisory Council and leadership of the Charles Pankow Foundation during a presentation of the research study at a Council meeting in June 2007 in Portland, Oregon. The Advisory Council is composed of nine construction industry leaders from a diverse spectrum of the industry who provide guidance to the CPF Board of Directors and staff. The findings of the research were presented to the Council for consideration and input. Comments provided by the meeting participants were recorded and incorporated into the research where appropriate.

The last validation effort entailed distributing the study findings to the previous study participants for their confirmation of the results. Each of the questionnaires used for the benchmarking and innovative product surveys asked the respondents whether they could be contacted for further information. A list was created of those who responded positively to this question. The people who were interviewed as part of the case studies were also added to this list, creating a combined list of 85 people (47 from the benchmarking survey, 30 from the innovative products survey, and 8 from the case studies). A questionnaire was developed (see Appendix 9.6) that contained the guidelines, suggested practices, and factors that were found to influence innovation. The questionnaire asked the respondent to rate the impact of the factors on innovation and to provide additional comments. For each factor, the questionnaire also asked the respondent to provide an implementation example and a justification for the rating. The questionnaire was e-mailed to the list of 85 people. Thirteen of the e-mails were returned as undeliverable and, therefore, the questionnaire was distributed to 72 people. The responses to the questionnaire were recorded in a spreadsheet for analysis. The results from the validation effort are provided in Section 5.4 of this report.

4.0 RESULTS

4.1 Respondent Demographics

4.1.1 Benchmarking Survey and Interviews

A total of 79 survey responses were recorded from the interviews (10) and on-line questionnaire (69). The responses came from a wide variety of construction industry personnel including personnel in the positions of company president, CEO, COO, project manager, and estimator. The years of experience of the respondents in the A/E/C industry ranged from three to 50 years (mean and median = 26 years). The respondents work for firms that are both small and large. The annual revenue of the respondents' firms ranged from $900,000 to $3.2 billion (mean = $296 million; median = $43.5 million). Sixty-three percent of the responses came from personnel located in primarily the West Coast states (CA, OR, WA), and the remainder (37%) came from other states across the country (AL, CO, FL, HI, IA, IN, KA, KY, MA, MI, MO, NE, NJ, NY, OH, PA, TX, and VA).

The respondents were asked in the survey about the types of facilities which their firms work on and the services which their firms provide. Commercial/office buildings are the most common type of facility worked on (67% of the firms). Industrial (45%), manufacturing (42%), and multi-family residential (35%) were also the predominant types of facilities designed and constructed by the respondents' firms. The approximate distribution of services provided by the respondents' firms are, in decreasing order, general contracting (37%), specialty contracting (19%), construction management (19%), engineering design (8.5%), and program management (5.3%). On average, 57% of the projects worked on by the respondents' firms are privately funded, while 43% are publicly funded. The majority of the projects worked on by the firms (72%) are new construction; 23% are renovation projects and 5% repair/remodel projects.

One survey question asked about the approximate percentage distribution of project delivery methods in which the respondent's firm participates. As shown in Figure 6, Design-Bid-Build is the most common delivery method. Thirty-two percent of the firms participate in this delivery method. This is followed by Design-Build (22%) and CM/GC (20%) with significant percentages. It is interesting to note that a significant percentage of the projects (50%) are delivered under project delivery methods which formally integrate design and construction expertise (Design-Build, CM/GC, CM @ Risk, and CM).

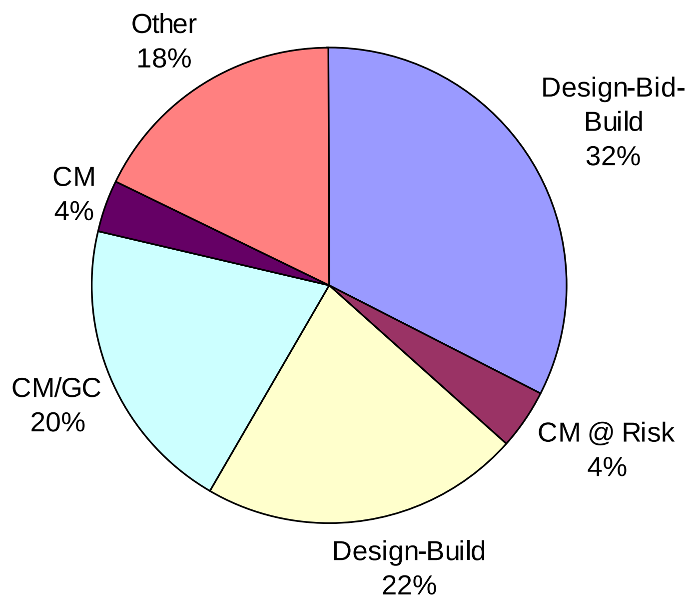


Figure 6. Project Delivery Methods in which the Responding Firms Participate

When asked specifically about the Design-Build team structure, the respondents' firms which take part in Design-Build projects participate in a variety of forms (see Figure 7). The firms predominantly either subcontract a portion of the work to another firm (28%) or perform both the design and build services with internal capabilities (23%).

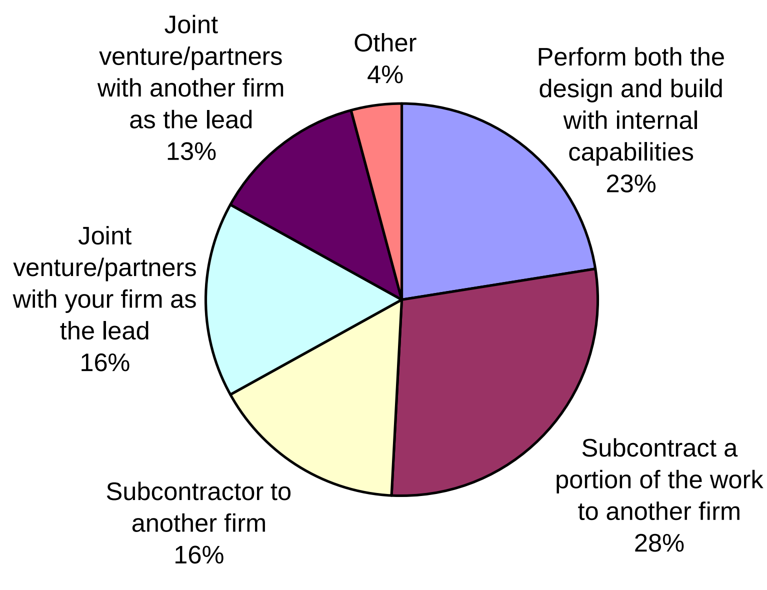


Figure 7. Design-Build Team Structure

4.1.2 Innovative Products Survey

The questionnaire sent to the 189 firms which have developed products for implementation in the construction industry was completed and returned by 34 respondents (18.0% response rate). The respondents who completed the questionnaire had experience working in the construction industry that ranged from 2 to 46 years (mean = 23.3 years), and held a variety of positions including: President, CEO, CIO, Project Manager, Technical Director, Marketing Director, and Scientific Director. The services provided by the firms in which the respondents work are primarily: engineering design (36%), construction management (27%), specialty contracting (18%), and general contracting (12%).

The 34 innovations developed by the responding firms can be grouped into the following categories: information technologies (3), computer-based technologies (3), construction equipment (6), construction means and methods (8), and facility end products (14). Appendix 9.7 provides a list of the products along with a short description. The products are used by many different types of firms. The products are primarily used by engineering design firms (52%) and construction management firms (52%), followed by general contracting firms (50%); specialty contracting firms (29%), program management firms (26%), and architectural design firms (19%).

When asked the extent of their involvement with the product, 62% 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. The questionnaire asked about the level of resources invested in R&D of the product. On average, the firms expended 4,677 worker-hours in R&D for the products over 38.4 months, and invested $836,000.

A variety of organizational elements are employed by the firms related to innovation (see Figure 8). 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. Seventy percent of the firms have an innovation budget. A formal innovation plan exists within 58% of the firms, and 56% have formal innovation meetings. It is clear that the product manufacturers incorporate innovation to a great extent into the organizational structure and climate.

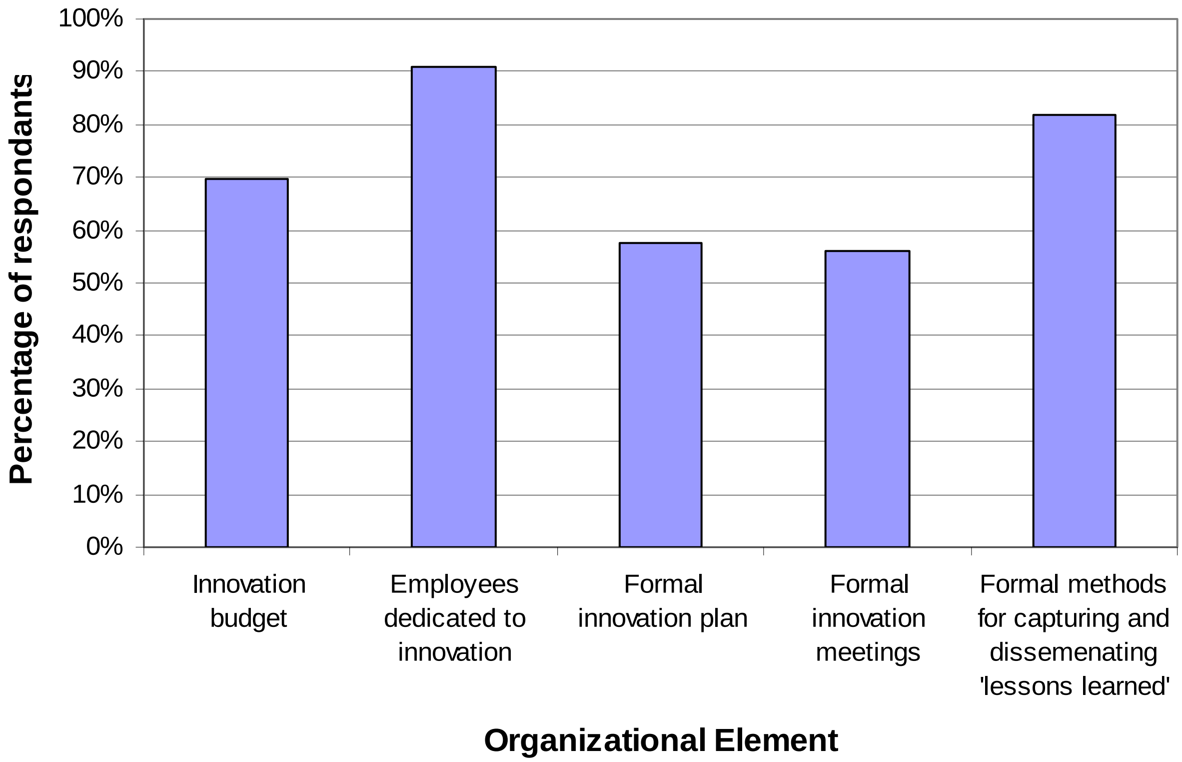


Figure 8. Organizational Elements related to Innovation (Innovative Products Survey)

4.1.3 Project Case Studies

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 was not collected, the contacts either did not respond or said that they were not interested in participating in the study. A summary of the projects is provided in Table 1 below. Additional information about the projects is provided in Appendix 9.8.

The projects are located in nine different states across the U.S. within the Southwest, Northwest, Midwest, Southeast, Northeast, East Coast regions. In terms of size, based on approximate dollar value, two of the projects are small, four are medium, and four are large. Most of the projects (7) were new projects, while the remaining (3) were renovation projects. The types of project delivery methods utilized on the projects included both integrated delivery methods (5), such as design-build and construction manager/general contractor, and the traditional design-bid-build method (5). The sample consisted of both publicly-funded and privately-funded projects. Six projects were privately-funded, and four were publicly-funded. Seven of the projects came from the award-winning projects list, and the other three were from the regular projects list.

Table 1. Case Study Demographics

Project	Location (State)	Size	Type	Delivery Method	Funding Source	Status
A	OR	Small	New	DB	Private	Award
B	MI	Large	New	CM/DB	Private	Award
C	NV	Medium	New	DBB	Public	Regular
D	CA	Large	New	DB	Private	Award
E	FL	Medium	New	DBB	Private	Regular
F	WA	Large	New	DBB	Private	Award
G	GA	Small	Renovation	DB	Public	Regular
H	MD	Medium	Renovation	DBB	Public	Award
I	MA	Large	Renovation	CM/DB	Public	Award
J	CA	Medium	New	DBB	Private	Award

A total of 23 interviews were conducted on the ten case study projects. Interviews were conducted with the owner, 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 addition, for the award-winning projects, people involved in the innovative efforts on the projects were targeted for interviews. In many cases, the number of interviews was limited by the availability and interest of the people targeted.

4.2 Innovation in Practice

4.2.1 Types of Innovations

The benchmarking survey and interviews asked the respondents: “What new products, technologies, or processes, that either your firm developed or were developed outside your firm, have been implemented on your projects or within your firm in the past 10 years?” A total of 76 innovations were listed in all of the responses to this question. The innovations ranged to a great extent and can be grouped into six categories: Information Technologies; Computer-based Electronic Devices; Design and Construction End Products; Construction Means and Methods; Contracting; and Other. Of the 76 innovations, those listed by three or more respondents, and those that are otherwise notable, are shown in Table 2.

It should be noted that not all of the innovations mentioned in the survey responses fit within the definition of innovation as established for this research study. Some products and processes that were mentioned by the respondents were trivial in nature, a solution to solve a problem on only one project, or a different design feature that is aesthetically pleasing.

The products developed by the 34 respondents to the innovative products survey can be grouped into similar categories, as described previously, and are also listed in Table 2 for comparison.

Table 2. Types of Innovations

Category	Benchmarking Survey	Innovative Products Survey
Information Technologies	Internet-based project management (8) Estimating templates (4)	Project information management system (1) Lessons learned systems (2)
Computer-based Electronic Devices	3D CAD (7) Personal Digital Assistants (3) GPS Grade Control (4)	Bid Express Project control system Leak noise correlator
End Products (Design and Construction)	New forming systems (9)	Material products (5) Mechanical products (7) Electrical products (2)
Construction Means and Methods	Work platform to allow workers to operate over water (1)	Concrete formwork/placement (5) Task management (2) Welding (1)
Contracting	Innovations in Design-Build (6) Partnering (1)	
Construction Equipment		Heavy/civil equipment components (5) Concrete materials washout (1)
Other	LEED (1)	

Innovations were identified on the case study projects as well. During the interviews the participants were asked to identify what was innovative about their project. In some cases the innovations that the interviewees identified did not fit within the definition of innovation developed for the research study. For example, a unique architectural style of a building which may be different than other buildings would not be considered as an innovation unless changes needed to be implemented in the design and/or construction of the building which were later adopted on other projects. The innovations identified in the case studies which fit within the definition of innovation as part of this study include:

- Unique green design and construction features
- Heat transfer systems embedded in the rock formations below a building
- A “living” roof
- Phytoremediation to rid soil of contaminants
- A new “organic” structure based on the concept of the human rib cage
- Unique 3D imaging during design
- Internal bracing design to shore up interior walls
- Ground freezing to solidify the soil

4.2.2 Sources of Innovations

Several questions in all three parts of the study were aimed at exposing where innovative ideas begin. In the benchmarking study the respondents indicated that approximately 54% of the innovations start within the firm while the remainder (46%) come from outside the firm. When asked specifically about those innovation that originate internally and the source of the innovative idea, project manager was mentioned by 69% of the respondents, the most of any other internal source. Upper management (63%) and superintendent (51%) were also mentioned frequently. Other personnel involved in projects were mentioned to a lesser extent: foreman (35%), project engineer (32%), field worker (23%), and project architect (17%).

The benchmarking study also asked the source of innovations that originate externally. Slaughter (1993) highlights builders as primary sources of innovation because they take the inventions and put them to practical use, and because of the increasing needs of owners. The survey respondents identified suppliers as the primary external source of innovation (54% of respondents). Other sources commonly mentioned were: owner (29%), architect (28%), design engineer (24%), subcontractor (24%), and other industry (24%).

In the innovative products survey, most of the respondents (73%) indicated that the products were independently generated by their firm. Products were adopted from another industry by 15% of the respondent firms, and the remaining adopted the technologies from another firm within the A/E/C industry.

4.2.3 Innovation Rate

To learn about the rate at which the construction industry innovates, the benchmarking survey asked the respondents how often new products, technologies, or processes are introduced on their projects or in their firm. There was a very wide range of responses to this question, from zero up to 125 innovations per year. Fourteen of the 79 respondents (18%) reported ten or more innovations per year. Moreover, the mean number of innovations per year for all of the respondents was high at 5.9 (median = 2.0). Given the wide range of responses to this question, it was felt that there was perhaps some misunderstanding amongst the respondents regarding this question and what was meant by an innovation. A definition of innovation was provided in the questionnaire to identify what would be considered an innovation and what would not. The very high number of responses from some of the respondents indicates that perhaps their view of what constituted an innovation was outside of that framed within the definition given. However, for the respondents who were interviewed in person, which provided the opportunity to discuss the definition of an innovation, the mean rate of innovation was even higher at 12.4 innovations per year. As a result, the responses to this question were not used in the analysis.

For those innovations that do occur, the respondents in the benchmarking survey reported that on average there are approximately 180 worker-hours expended on developing and implementing each innovation. The average amount of time it takes from initial concept through implementation of an innovation in the respondents' firms is 4.7 months.

4.2.4 Motivation for Innovation

The survey respondents and personnel interviewed in the case studies were asked to indicate the impetus for the innovations. A summary of the responses from the benchmarking survey is shown in Figure 9a. The most common response was cost savings, which was identified by 64 of the 79 respondents (81%). This was followed closely by increasing productivity/efficiency

(77%) and improve quality (69%). Schedule reduction and creating a competitive advantage were also highly ranked.

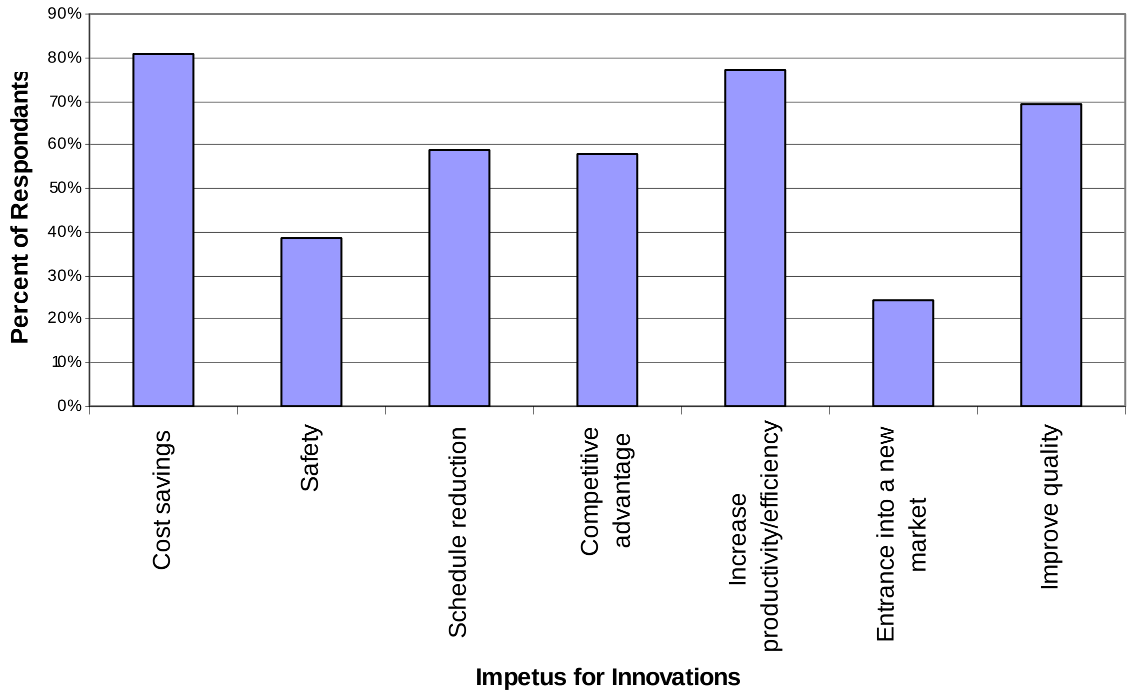


Figure 9a. Motivation for Innovation (Benchmarking Survey)

The innovative products survey asked the respondents to rate various reasons for innovation as to the extent, from none to extreme, to which the reasons were a motivator for the innovation. Figure 9b 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.

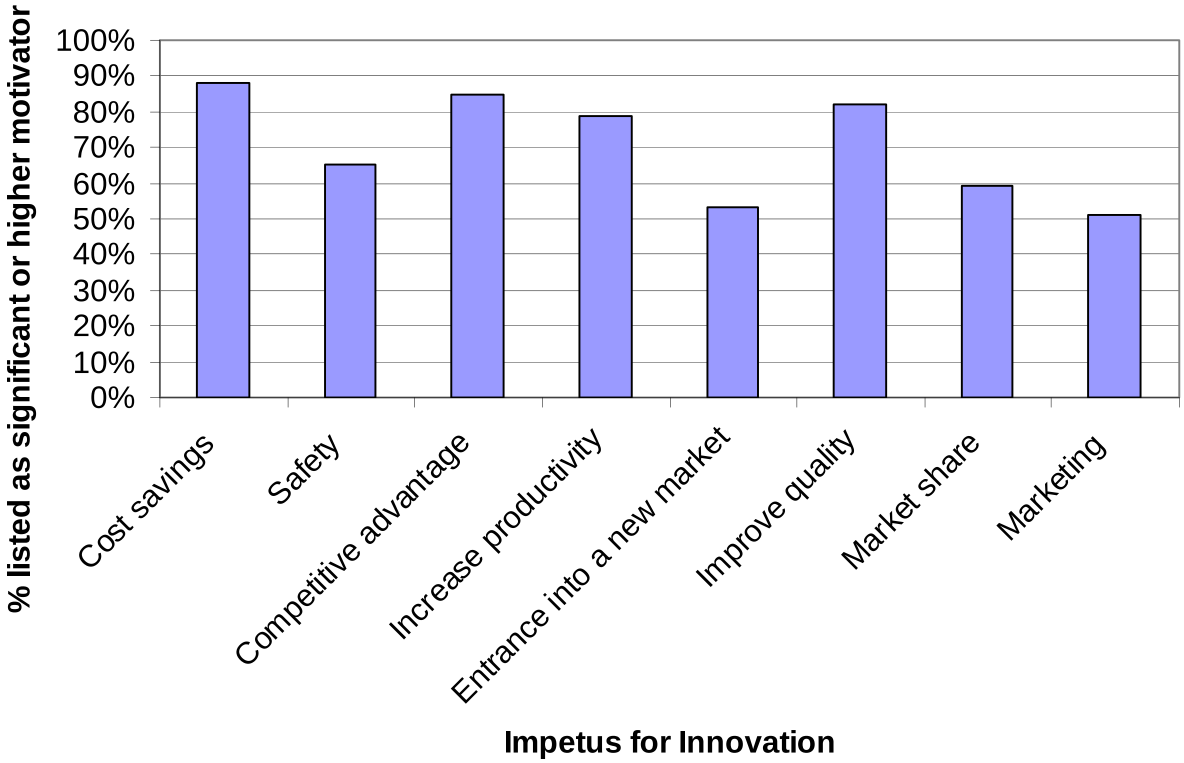


Figure 9b. Motivation for Innovation (Innovative Products Survey)

4.2.5 Enablers of Innovation

Enablers of innovation were also addressed in the surveys and interviews. In the benchmarking survey, support from the upper management of the firm was the most commonly cited factor that enables innovation. Fifty-three of the 79 respondents (67%) cited upper management support as important to successful innovations. This was followed by the level of communication within the firm (53%) and a culture of innovation (43%). A roughly equal level of importance was placed on the level of communication amongst the project team members (37%), the complexity/sophistication of projects (37%), and overlap of design and construction phases (36%).

The benchmarking survey respondents were also asked to rate using a scale of 1-5 (1 = high ability to innovate; 5 = low ability to innovate) their firm's ability to innovate within specific project delivery methods. The results from this question are shown in Figure 10. Design-Build was rated as the delivery method that allows the greatest ability to innovate, receiving an average rating of 1.7. This was followed by CM/GC (2.4), CM @ Risk (2.8), CM (3.3), and Design-Bid-Build (3.5). These results are similar to that found in the literature. Those project delivery methods which are structured to permit more integration of design and construction expertise tend to promote innovation to occur.

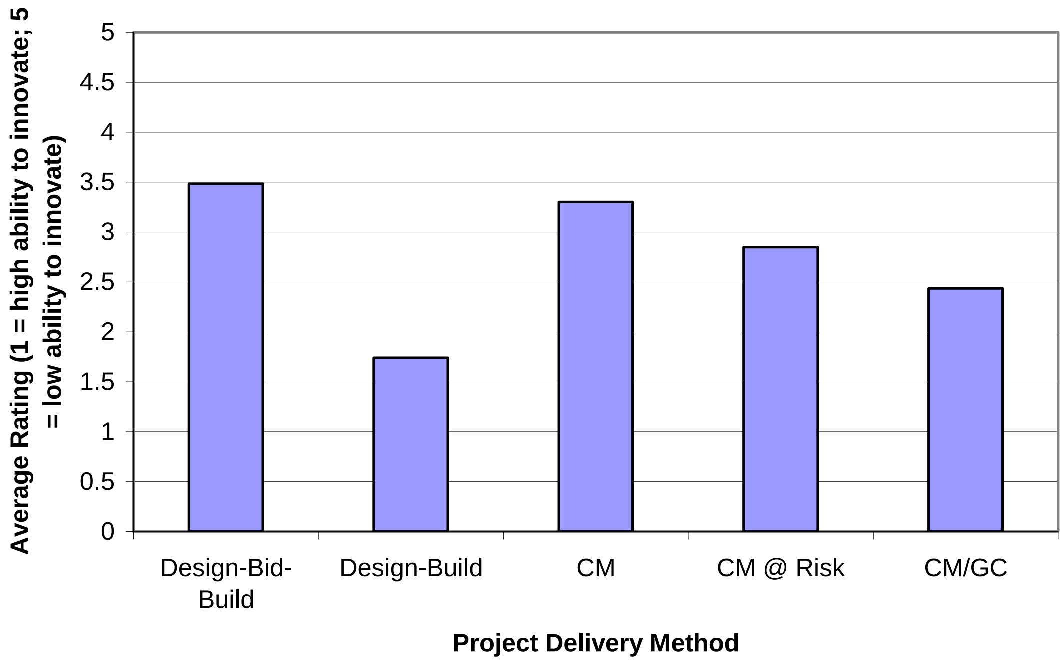


Figure 10. Ability to Innovate within a Project Delivery Method (Benchmarking Survey) (Note: A lower number indicates a greater ability to innovate.)

The innovative products survey revealed a variety of enablers as well. The respondents were asked to rate, from none to extreme, the extent to which certain factors enable the implementation of the innovative products. That is, the product developers/manufacturers were asked to assess what facilitates implementation of the products on construction projects. Similar to the benchmarking survey, support from upper management of the firm received the most significant or higher ratings (82%). Other enablers which were most commonly rated as significant or higher enablers of implementation of the innovations were: owner/client support (80%), organization culture (79%), an innovation "champion" within the firm (76%), communication amongst the project team (71%), and communication within the firm (65%). Project delivery method and the overlap of design and construction were not considered as strong enablers, receiving significant or higher ratings by 27% and 25% of the respondents, respectively. This result does not compare to the benchmarking survey which indicated these as strong enablers. Developers and manufacturers of products generally feel that their products can be implemented regardless of the project contracting strategy and phasing.

Those interviewed as part of the case studies identified similar enablers of innovation. The project owner's influence was frequently identified. The owner's vision, personal involvement and expertise, inclusion of innovation as a project goal, and level of investment of resources in innovation were included in the participant's responses. The ability of upper management to facilitate and promote innovation was also frequently cited as an enabler. The respondents felt that when upper management of a firm supports an innovation or the innovation efforts of employees, innovation is enhanced. Other factors that enable innovation which were frequently cited 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 amongst the project team members. Additional background information about the enablers of innovation is available in each project summary (see Appendix 9.8).

4.2.6 Barriers to Innovation

Barriers to innovation were explored in the study as well. Figure 11a shows the results from the benchmarking survey. When asked about what barriers exist, either within the respondent's firm or external to the firm, which limit innovation within the respondent's firm, the most common responses from the benchmarking survey were: not applicable to all projects (41%); not recognized by clients (40%); and fear of change (36%). Competitive bidding was also identified by a significant number of the respondents (31%). This result correlates with the results of related to enablers, which shows the respondents' lower rating of Design-Bid-Build as a delivery method that allows for innovation. Other barriers to innovation that were noted by a significant percentage of the respondents are: low return on investment (27%); long payback period (26%); industry regulations and codes (23%); low investment in R&D (23%); and risk of failure (21%).

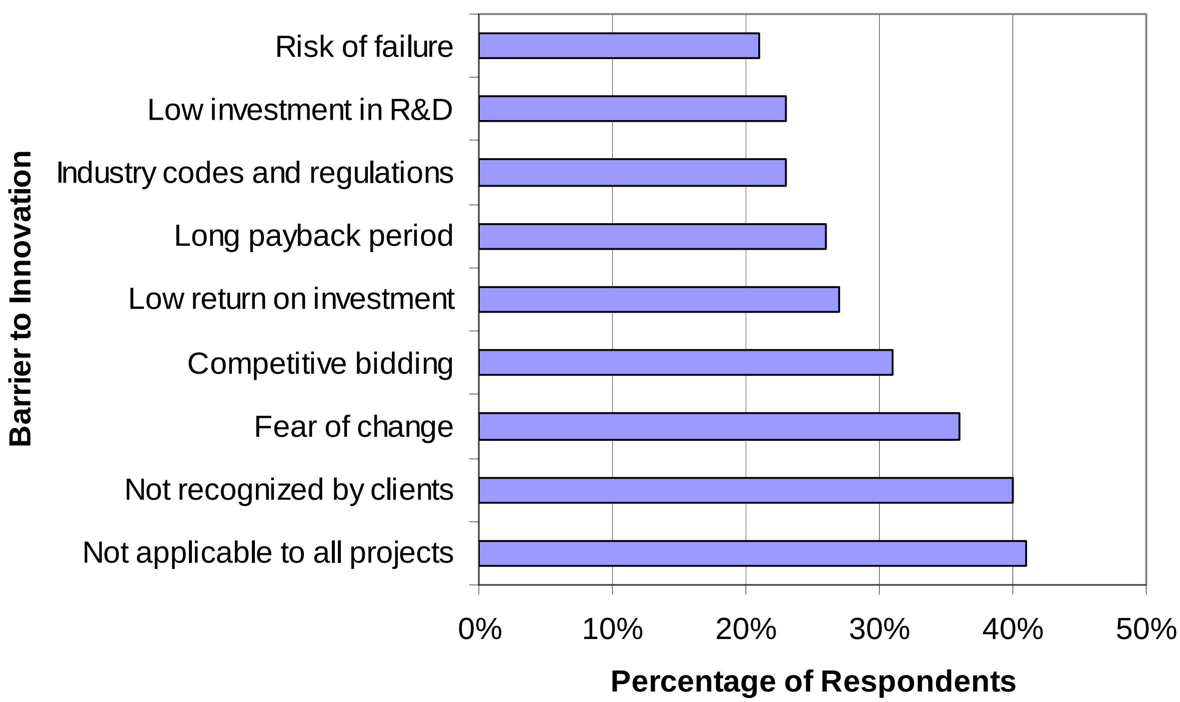


Figure 11a. Barriers to Innovation (Benchmarking Survey)

The innovative products survey respondents were asked to indicate the extent to which certain barriers affected the implementation of their products on projects. The respondents were asked to rate the impact of the barriers as: none, small, moderate, significant, or extreme. As shown in Figure 11b, fear of change was identified most often (by 53% of respondents) as a significant or higher barrier. Also highly rated as barriers were: not recognized by clients (35%) and lack of communication (24%).

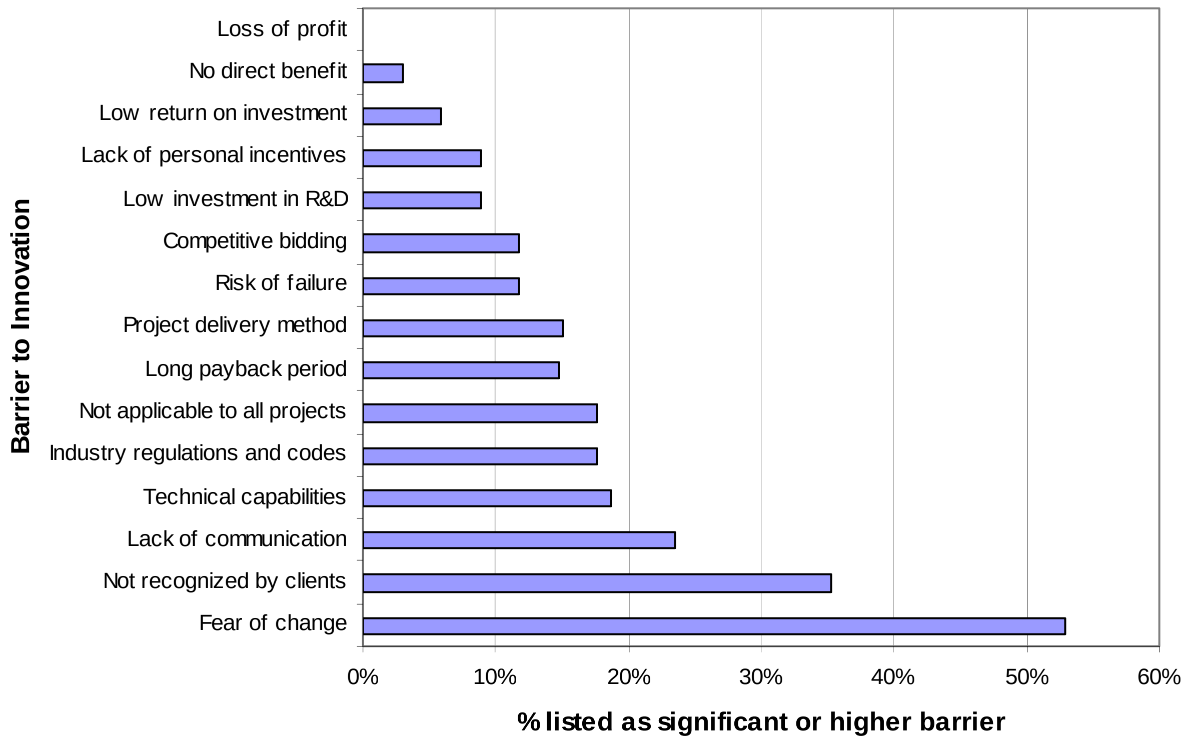


Figure 11b. Barriers to Innovation (Innovative Products Survey)

Similar barriers were identified by the case study participants. Out of the 10 case studies, the following were stated as barriers along with the number of projects on which it was listed as a barrier:

- Lack of or unilateral communication (7)
- No or low emphasis on employee and contractor recognition for innovation (7)
- Lack of resources for innovation allocated by owner (7)
- No resources provided for R&D (5)
- No innovation meetings (3)
- Innovation not part of owner’s vision (3)
- No time allotted to explore new ideas (2)
- No formal lessons-learned program (2)
- Fear of change and high risk (2)

- Design-bid-build project delivery method (1)
- Local, state, and federal codes (1)

4.2.7 Benefits and Outcomes of Innovation

Participants in the research study were asked to identify the benefits and outcomes of innovation. No limitation was placed on the type of outcome provided. While the respondents recognized that there are barriers to innovation, they also acknowledged that innovation does occur and has some benefits.

In the benchmarking survey, one question asked, "What are the impacts/outcomes of innovation within your firm?" The impacts which were most often cited by the respondents were: increased productivity (75%); cost savings (68%); improved quality (68%); and competitive advantage (61%). Other impacts of innovation, and the corresponding percentage of respondents who cited the impacts, were: increased market share (43%); improved safety (40%); marketing (33%); and appearance of new markets (31%).

The contribution of innovations to the profit of a firm was also investigated in the benchmarking survey. The respondents were asked how much the innovations in their firm contribute to the overall percentage of profit earned by their firm. The majority of respondents (43%) stated that innovations contribute only a small percentage to the firm's profit. A moderate percentage and a high percentage were cited by 29% and 9% of the respondents, respectively. Difficulties in linking innovations to profit may affect the responses to this question. Confounding factors can make it difficult to identify the impacts of an innovation on profit realized. Lacking a clear understanding of how innovation affects profit can negatively impact motivation to change and hamper attempts at innovation.

The outcomes identified by the respondents in the benchmarking survey were also commonly cited as motivators of innovation (see Figure 9a). Figure 12a shows a comparison between the benefits and motivators identified in the survey responses. As seen in the figure, some realized benefits were not identified as motivators for the innovations such as improved market share and marketing. It is interesting to note that schedule was identified as a motivator of the innovation, but not recognized as a benefit. However, schedule is closely related to productivity which is listed as a benefit.

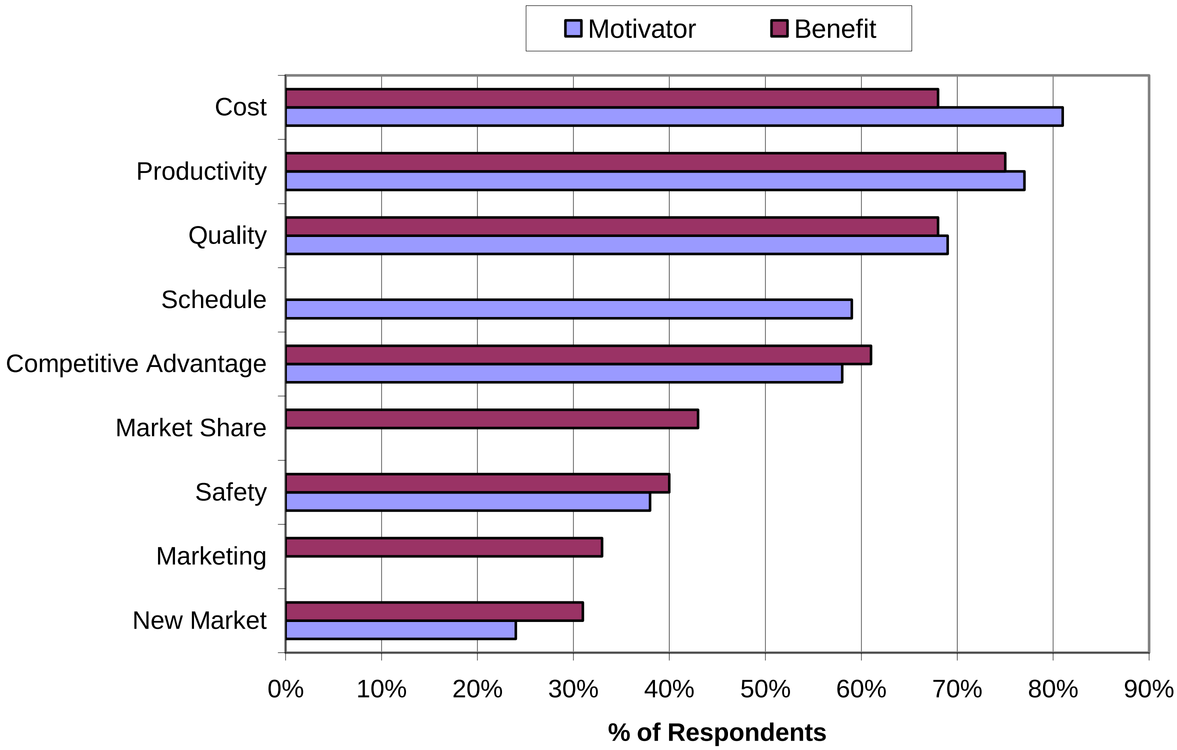


Figure 12a. Comparison of Benefits and Motivators (Benchmarking Survey)

The innovative products survey also included a question asking the respondents to rate the outcomes of their innovation. That is, to what extent do the innovation producers think certain outcomes are realized by the users of their innovation. Figure 12b 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.

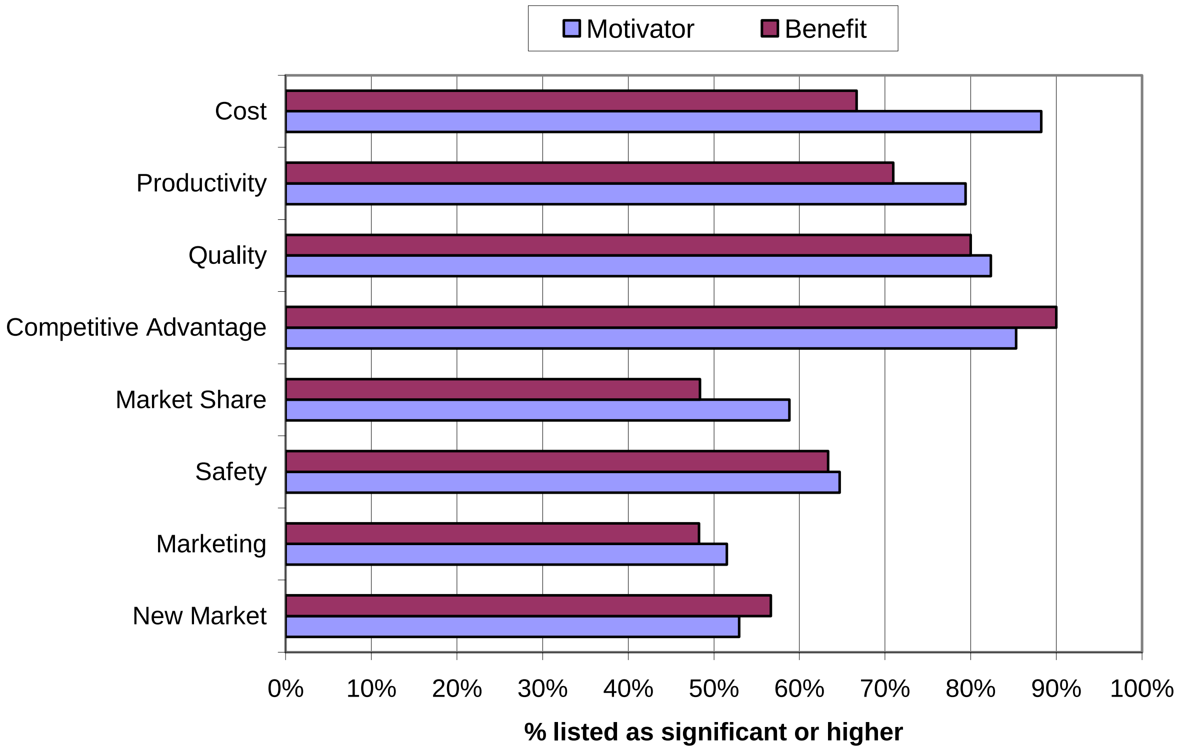


Figure 12b. Comparison of Benefits and Motivators (Innovative Products Survey)

The innovations on the case study projects resulted in a variety of benefits. Owner satisfaction was recognized as a benefit most often (6 of the 10 projects). On five of the case study projects (50%), the innovation contributed to the profitability of the project. Increased market share was also a common outcome, being recognized as a benefit on five case study projects. Other benefits from the innovations along with the number of projects on which they were recognized include: improved quality (5); increased productivity (4); shortened schedule (4); improved marketability/reputation of the firm (4); lower cost (3); and improved safety performance (2). On one case study project, construction cost and performance did not improve as a result of the innovations while other factors related to energy use, recycling, water quality, and environmental impact benefited.

4.2.8 Metrics and Assessment

Part of the research study was aimed at identifying metrics to measure innovation on projects. The surveys and interviews solicited input on the metrics used in industry to assess the impact of an innovation and the success at innovating.

On the benchmarking survey, several questions were asked that pertained to the firm's assessment and tracking of innovations and the metrics used in the process. With regards to the question, "How does your firm measure the success/failure of an innovation?", project team input/comments was cited most often (50% of the respondents). The other means for assessing the performance of an innovation which the respondents cited frequently were: quality performance (45%); productivity analysis (42%); client feedback (41%); and budget analysis (40%). It should be noted that approximately 13% of the respondents stated that no assessment was conducted of the success or failure of innovations in their firm.

The benchmarking survey respondents were also asked to give there perception of how well the firm measures and tracks innovations, and how important it is to their firm. Figure 13 summarizes the responses to these questions. Most of the respondents rate their firms as having a low or moderate ability to measure and track innovations. Approximately 8% of the respondents stated that they have no ability to measure or track innovations. With regards to the importance placed on this assessment effort, the most common response was that it is moderately important (37%). Roughly an equal number of respondents feel that it is minimally important (24%) as those that feel it to be significantly important (23%).

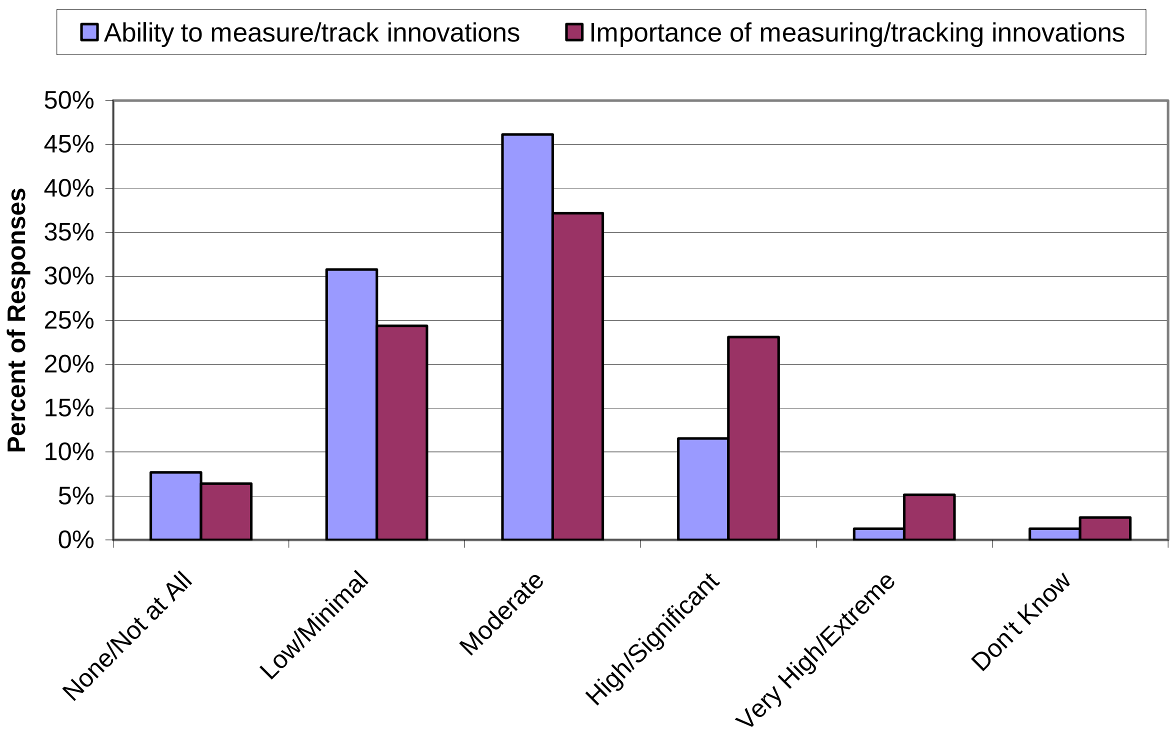


Figure 13. Ability to Measure/Track Innovations and Importance of Measuring/Tracking Innovations (Benchmarking Survey)

In the innovative product survey, the respondents were asked to rate the ability of listed metrics to track and measure the effectiveness of the innovation. The metrics recorded from the benchmarking survey were listed for their consideration. As a means of tracking and measuring innovation effectiveness, client feedback was rated as significant or higher by the most respondents (79%). The next highest rated means of tracking and measuring innovation were: productivity analyses (73%), project team input/comments (73%), quality performance (67%), and budget analyses (64%). Safety performance (56%), schedule performance (42%), and market share (42%) were also highly rated.

4.3 Additional Comments

The survey and interview participants were also presented the opportunity to provide additional comments related to the research topic. Many additional comments were received that provide additional insight into the innovation process. Below is a sample of the comments offered:

What is driving innovation?

- The most important and relevant innovation in our industry today is the increasing demand by owners for, and industry's use of, integrated project delivery methods.
- I think the environment for innovation is getting better. I do think the driving force behind this change is design-build collaboration thinking versus the typical competitive bid environment.
- In most cases you've got to be in it for the long haul. Unless there is an immediate observable return on investment, changes to long held practices take time and sustained effort. The final results are usually worth it.

Factors that limit and enable the ability to innovate:

- The industry is steeped in tradition; experience counts in the assignment and gathering of power.
- Changes are hardest on those whom have excelled in traditional settings -- catalysts for substantial change at the top echelon of an organization are therefore hard to find. Most understand the value of innovation and improved methods in executing construction tasks -- but rarely are willing to risk precious political capital to promote, inspire, and 'walk the walk'.
- My experience with the AEC industry is that participants are very traditionally focused and risk adverse.
- Our industry has one way to do something, when a change comes to us it is rare that it works. If something does take hold, it takes years before it is known to work in the industry and is often much more costly than the standard.
- It takes significant time, energy and a strong commitment to the innovative vision in order for innovation to thrive.
- Having an owner that knows the right questions to ask was a huge benefit.
- Bidding on projects that are associated with progressive, innovative and challenging owners will lead to innovation.
- Design-build allowed the opportunity for innovation in comparison to typical public design-bid-build arrangements.

Interesting observations and trends:

- In Chicago, L.A., New York, and other "competition" centers, techniques are being employed because they have to be to survive. For instance, at Fluor Daniel, CAD work is being farmed out overseas. In Chicago, Seattle, et al., BIM technologies are being implemented and improved. In secondary and tertiary markets, technology is lagging.

- There is great disparity between the average firms and top firms when it comes to innovation. My instincts tell me the average firms do nothing to innovate while the top firms constantly innovate. However the average firms make up 75% of the market and the top firms perhaps 1%.
- Construction is geographically constrained; requiring local resources, local knowledge, skills, etc., with very little opportunity for the supply chain to introduce unique or fundamentally different offerings. It is not beset with fierce global competition similar to other industries....where having the next best idea or way of doing something is key not to just profitability, but to survival.

5.0 ANALYSIS AND DISCUSSION

Analyses of the data collected were conducted to determine the factors that impact innovation on a project and how to assess and measure the potential for innovation and success at innovation. The analyses utilized the data gathered from the benchmarking survey, innovative product survey, and case studies along with the information recorded from the literature review. Both quantitative and qualitative analyses were conducted. For open-ended questions in which the 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.

5.1 Presence of Innovation (Lagging Indicators)

Returning to the definition of innovation established for the research study, 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. 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.

It may be the case that a project experiences multiple innovations. When multiple innovations create change over time, the frequency of the change can be measured. The frequency with which change occurs is also an indication of the magnitude of innovation. Therefore, the research considered the number of feasible new ideas implemented over the course of each project. The extent to which the innovative process is occurring is not only reflected in the number of new ideas implemented, but also in the number of feasible new ideas generated and tested. Generating, testing, and evaluating new ideas may or may not lead to new products, processes, or systems implemented. However these efforts are an indication of whether the innovation process is present and whether innovation is occurring.

As stated previously, the innovation must also be diffused beyond just the initial project or setting in which it is employed. Lacking diffusion to other projects within a firm or the industry, the change is simply problem solving. Its value to the firm and industry is validated when it is accepted and applied after its initial demonstration and use. Therefore, the extent and speed to which a new product, process, or system has diffused throughout a firm or the industry is an indicator of whether innovation has occurred. This aspect of innovation was evaluated in the research as well.

Implementing an innovation often requires education and training of those who put the innovation into practice. This is especially true of non-trivial change which requires significant modifications to work practices and conditions. This can be accomplished by providing continuing education and training for current employees or by hiring new employees who have specialized skills and knowledge. Hence, the amount of new training and education that is required for employees as a direct result of changes in their work can also reflect the innovation that occurs. The research utilized the amount of required employee training and education as an indicator of innovation.

Literature identifies other impacts from innovation that include: increased profit, lower cost, decreased schedules, improved safety performance, improved quality, increased market share, and the presence of a competitive advantage. These benefits were exposed in the benchmarking survey as well. The extent to which these impacts occurred on the case study projects was also used as an indicator of whether innovation occurred on the projects.

In summary, the following factors were used as indicators of whether innovation occurred and the extent of innovation on the projects evaluated in the research study:

- Change in, and impact of, work products, systems, and processes
- Number of feasible new ideas generated, tested, and implemented
- Amount of new training and continuing education required for employees as a result of changes in their work
- Extent and pace of diffusion to other projects and industry
- Impact on: profit, cost, schedule, safety, quality, market share, and competitiveness

The strength of the relationship between each factor 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 tie to innovation. Many different project characteristics and processes can create the impacts and it is difficult to isolate innovation as the causal factor.

5.1.1 Case Study Projects

To determine the extent of innovation on the case study projects, each of the lagging indicators described above was evaluated by the researchers on each project. Using the information gathered during the case study interviews and the definition of innovation established for the study, the researchers assessed each factor using a rating scale. 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 1-10 was used with 1 indicating none and 10 indicating significant/extreme. For the assessing the secondary indicators (project, cost, schedule, etc.), a 1-5 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 that innovation was the driver of the impact. Each project was rated based on all of the indicators, and the ratings were summed to create an innovation score for the project. Table 3 shows the total innovation score for the projects. A higher score indicates increased innovation. The innovation scores ranged from 10 to 60, with a mean score of 37.8 (median = 36). 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.

Table 3. Case Study Innovation Scores

Project	Innovation Score (from researcher evaluation of each project)	Innovation Success Self-Assessment Score (from interview responses)
A	60	19
B	59	22
C	21	19.5
D	49	31
E	10	20
F	59	6
G	11	2
H	35	17
I	36	22
J	--	--

As part of the case study interviews, the participants were asked to rate the extent to which innovation contributed to the success of the projects. The participants were asked to rate on a scale of 1-5 (1 = not at all; 5 = excellent) the contribution that the innovation(s) on the project had on: profit, schedule, quality, productivity, safety, market share/reputation, and overall owner satisfaction. The participants were also asked whether the innovation(s) were used on subsequent projects. Weighted averages were calculated for each factor, which were then summed to create an innovation success self-assessment score. The scores from each participant were averaged to determine a combined score for the project. The results are shown in Table 3. A higher score represents greater innovation. It should be noted that the scale used for the innovation score given by the researchers is different than that used in the interview responses. For example, a score of 35 would be an average innovation score based on the researchers' rating, but would indicate a high level of innovation using the interview participant responses. For each score, though, a higher value indicates a higher level of innovation.

As seen in the table, the distribution of innovation scores developed by the researcher team is different than that from the participant self-assessment. This difference may be due to the different perspectives of the researchers and case study participants. The ratings provided by the research team are believed to more accurately reflect the innovation on the project as defined in the research study. In their evaluation of the projects, the research team maintained its focus on what constitutes innovation. The research team also has the benefit of comparing one case study project to another to rank the projects based on innovation, and of comparing the innovations to those identified in the benchmarking survey and innovative products survey. This perspective is not available to the interview participants. Therefore, analyses comparing practices and project characteristics described below utilized the innovation scores developed by the researcher team.

A simple comparison of the award-winning and "regular" projects based on innovation scores developed by the researchers is shown in Figure 14. The figure shows the average innovation scores for the award-winning projects (49.7) and the regular projects (14). It is evident from the figure that the award-winning projects had a greater amount of innovation. This result supports the initial research hypothesis that award-winning projects are more innovative.

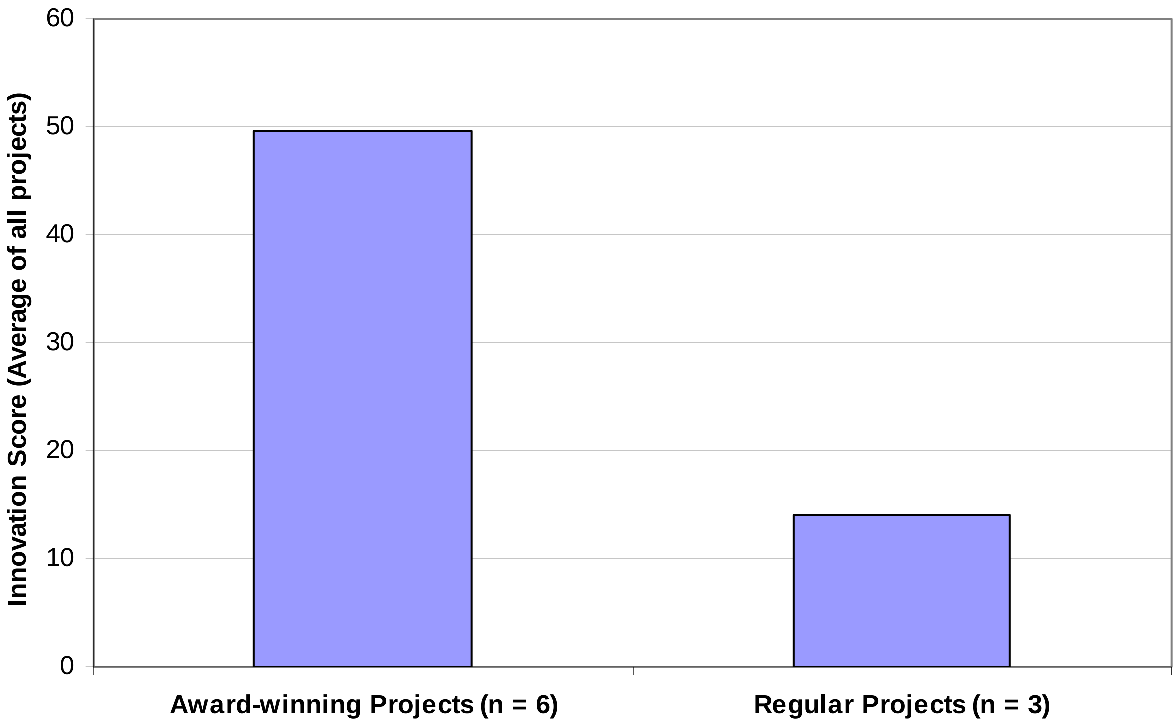


Figure 14. Comparison of Innovation Scores for Award-winning and Regular Projects

5.1.2 Benchmarking Survey

The benchmarking survey also provided an ability to calculate innovation scores. However, the benchmarking survey asked the respondents to provide input not based on one single project, but on the projects undertaken by the firm. Therefore the innovation scores calculated from the benchmarking survey represent innovation throughout the firm's projects while those from the case studies are on single projects. Nevertheless, the benchmarking survey can provide valuable insights to the factors that impact innovation (leading indicators) on projects.

As mentioned previously in this report, the responses regarding the innovation rate on the benchmarking survey (# of innovations per year) were felt to be unreliable. Therefore, in order to determine how innovation performance varies depending on firm and project characteristics, an aggregate benchmarking innovation score was developed using other questions contained in the survey questionnaire. This was done by combining the responses from four questions. The four questions used to calculate a benchmarking innovation score for each firm were:

- How would you rate the **level of innovation** that occurs on your projects and in your firm?
- How would you rate your firm's **ability to innovate** compared to other similar organizations in the A/E/C industry?
- How would you rate your firm's ability to **envision** new products, technologies, or processes?
- How would you rate your firm's ability to **implement** new products, technologies, or processes?

Each of these questions was answered using a Likert scale with five possible responses (e.g., very low, below average, average, above average, and very high). The responses were given points from 0 – 4 or 1 – 5 depending on the possible responses (0 for "None" or "Not at All"). A score was calculated for each firm by summing the points received on the four questions and then normalizing to a scale of 1 – 10. If, for example, a respondent gave the highest rating to their firm for all of the questions, the firm would receive an innovation score of 10, indicating that the firm has a very high level of innovation relative to other firms. A lower innovation score represents a lower level of innovation compared to other firms. The distribution of innovation scores for the responding firms is shown in Figure 15. The scores ranged from a low of 1.1 to a high of 9.5 (mean = 6.4, median = 6.3).

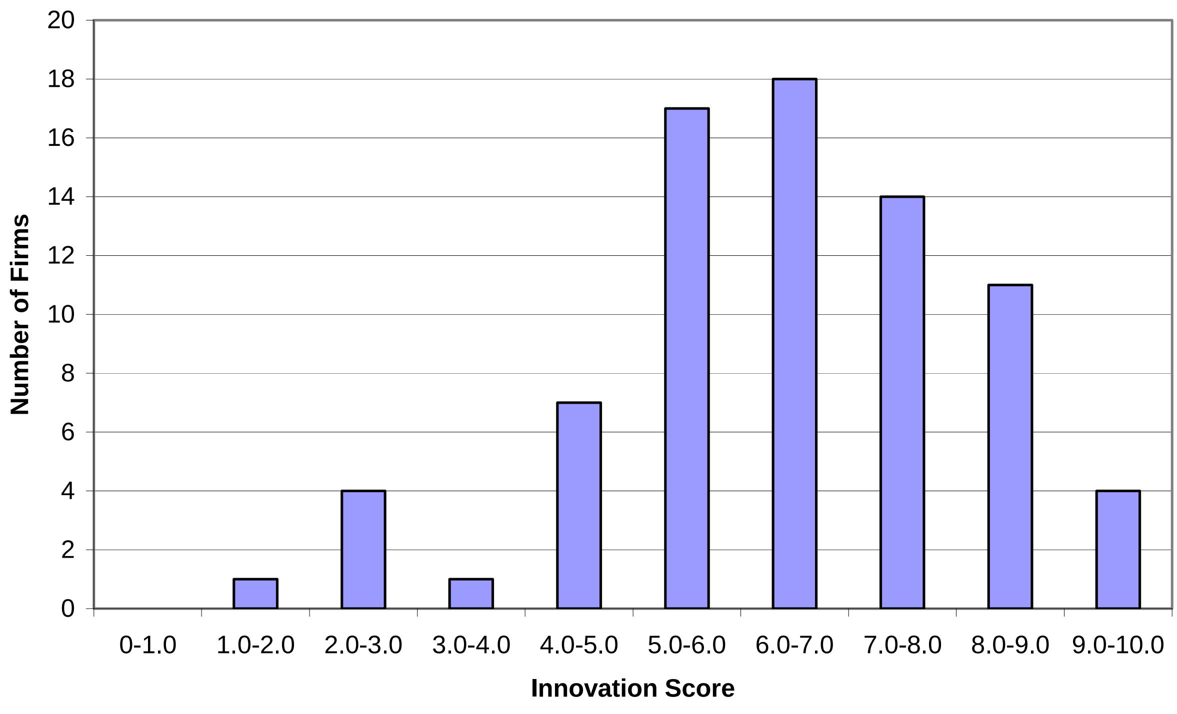


Figure 15. Distribution of Innovation Scores (Benchmarking Survey)

5.2 Innovation Enablers and Impacting Factors (Leading Indicators)

The next step in the analysis was to investigate the relationship between individual enabling and impacting factors (leading indicators) and the innovation scores calculated from the lagging indicators. Performance metrics identified in the literature review and innovative product survey were selected and evaluated. The analysis with respect to each metric is described below.

For each of the analyses, two sets of data were used to measure the leading indicators. The first set is the responses provided by those participating in the case study interviews. The respondents were asked to answer each question using a Likert scale with five possible ratings (1 = not at all; 2 = very low; 3 = average; 4 = significant; and 5 = excellent). A combined rating for each leading indicator was calculated for each project by summing the ratings received on all of the questions related to that leading indicator. A higher aggregate rating indicates greater owner influence.

In addition to the ratings given by the interview participants, the research team used its own judgment, knowledge of the projects, and knowledge of innovation and the construction industry to create its own rating of each leading indicator. A 1-10 scale was used (1 = not at all and 10 = excellent/extreme). The analyses below show the results using both ratings. For reasons similar to those described above related to the innovation score, the ratings given to each leading indicator by the research team are believed to be more accurate in their reflection of the influence of each indicator.

5.2.1 Owner Influence

The influence of the owner has been identified in literature as having an impact on innovation on a project. The owner sets the project goals and objectives, enters into contracts to get the project designed and built, and controls the level of resources (dollars, time, etc.) expended on a project. The case study interviews asked several questions regarding owner involvement which can be used to gauge the influence of the owner on innovation. These questions were:

- To what extent was the owner involved or interested in innovation?
- To what extent did the owner allow time to develop innovative ideas?
- To what extent was innovation a project objective of the owner?
- To what extent did the owner include innovation in the budget?

A comparison of the owner influence rating based on the interview participants' assessment and the innovation scores for the projects is shown in Figure 16a. The figure shows a moderate relationship between owner influence and innovation (R^2 = 0.32).

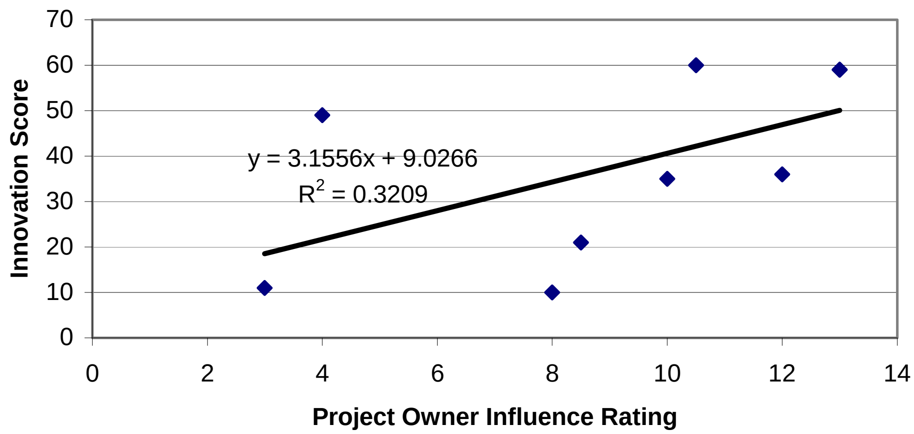


Figure 16a. Impact of Owner Influence on Innovation – Participant Ratings (Case Study Projects)

A similar comparison can be made between the owner influence rating based on the researcher evaluation and the innovation scores. Given the information collected during the case study interviews, the researchers rated the projects, using a scale of 1-10, according to the influence of the owner on innovation on the project. This relationship is shown in Figure 16b. The figure shows a much stronger positive relationship between owner influence and innovation (R^2 = 0.91) compared to the ratings given by the interview participants.

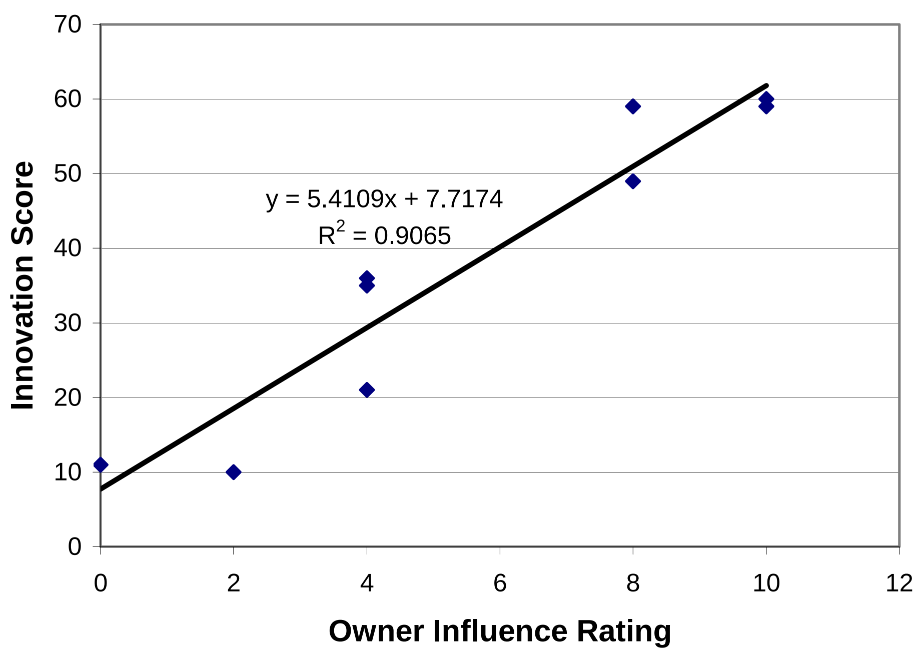


Figure 16b. Impact of Owner Influence on Innovation – Researcher Ratings (Case Study Projects)

5.2.2 Presence of an Innovation Champion

During the case study interviews, the participants were asked about the extent to which there was a champion on the project shepherding the innovation and eliminating potential roadblocks. The presence of a champion can be a significant factor in whether an idea gets implemented or not. Figure 17a shows the relationship between the presence of a champion based on the interview responses and innovation on the project. A moderate relationship ($R^2 = 0.32$) between a champion and innovation was exhibited in the case study projects.

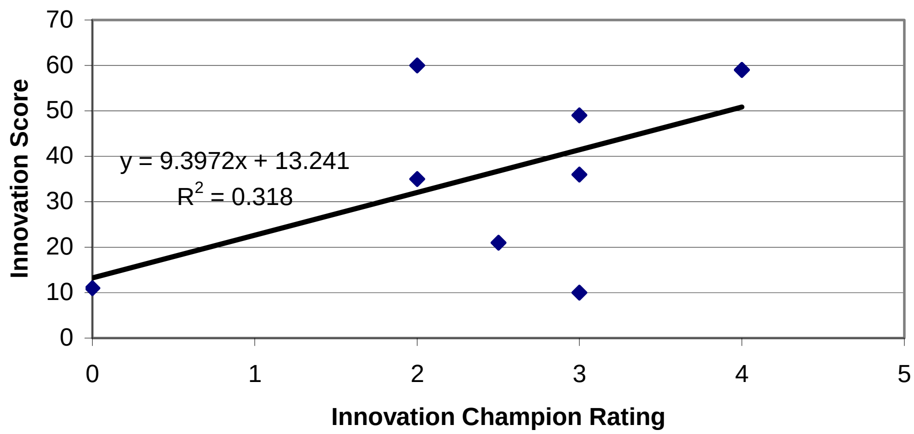


Figure 17a. Impact of Innovation Champion on Innovation – Participant Ratings (Case Study Projects)

Using the rating given by the researcher team as to the extent to which a champion was involved in the success of the innovation, a similar figure can be created (see Figure 17b). As seen in the figure, when an innovation champion was present to a greater extent in the case study projects, innovation was increased. The data show a strong relationship between an innovation champion and extent of innovation ($R^2 = 0.79$).

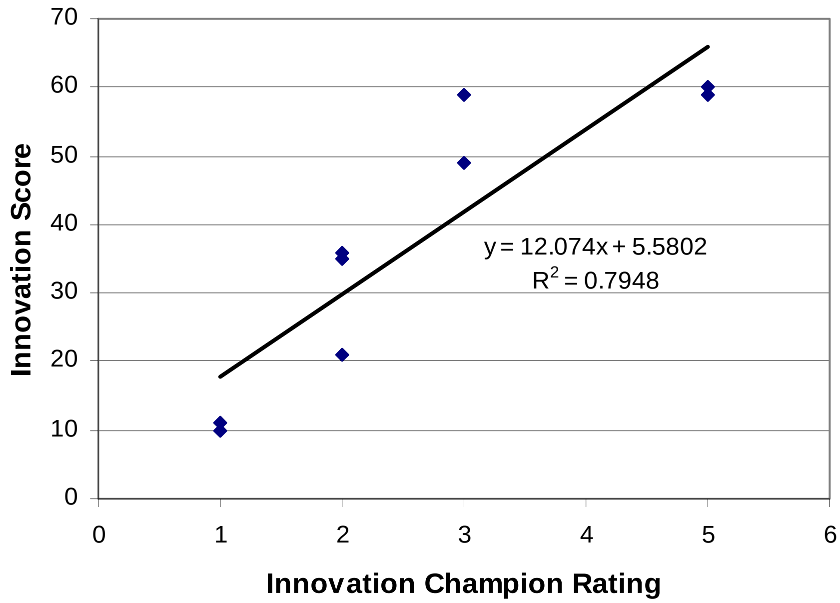


Figure 17b. Impact of Innovation Champion on Innovation – Researcher Ratings (Case Study Projects)

5.2.3 Project Team Collaboration

When designing and constructing projects, the work may be conducted through employees working together in teams or by employees working on their own. The collaborative nature of working in teams can benefit innovation by helping to foster new, feasible ideas based on the input of many individuals and enhance communication. This is especially true if the individuals come from diverse backgrounds and have unique perspectives. The collaboration can occur in face-to-face meetings, conference calls, via e-mail, or any other means of communication.

The case study interviews addressed collaboration by asking the participants about the extent to which the project team members worked together in groups. It is assumed that be working in groups, through any type of communication means (face-to-face, conference calls, e-mail, etc.), collaboration will result and innovation will be enhanced. Figure 18a shows the relationship between project team collaboration and innovation using the ratings provided by the interview participants. Figure 18b shows the relationship using the ratings created by the researchers. Both figures show a positive relationship (i.e., as collaboration increases, so does innovation) between collaboration and innovation.

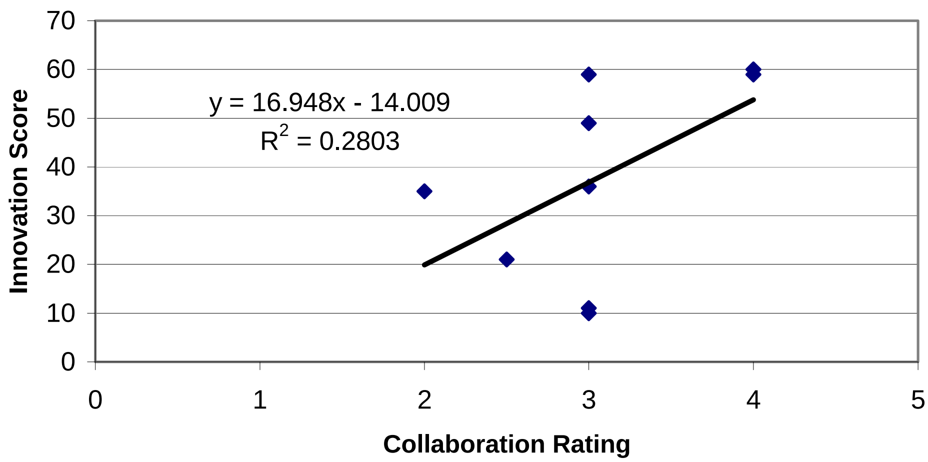


Figure 18a. Impact of Project Team Collaboration on Innovation – Participant Ratings (Case Study Projects)

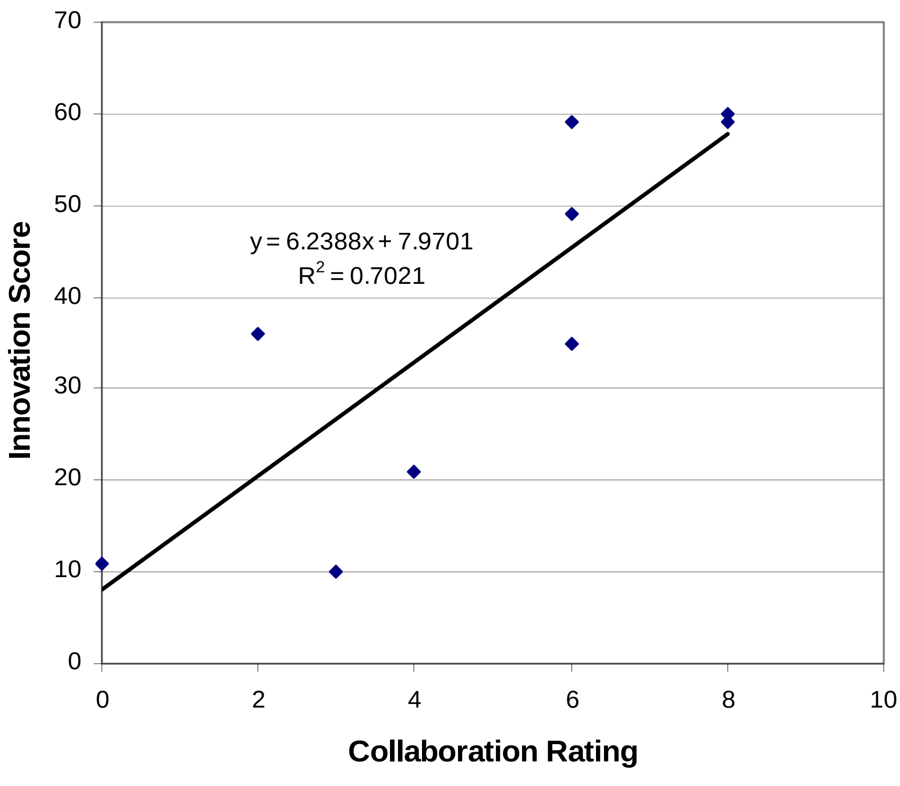


Figure 18b. Impact of Project Team Collaboration on Innovation – Researcher Ratings (Case Study Projects)

5.2.4 Degree of Project Team Integration

The degree to which different firms working on a project are integrated was also identified as a possible impact on innovation. The integration of firms with different areas of expertise, such as multiple design firms working together and design firms working with construction firms, brings together different perspectives that can facilitate the sharing of knowledge and promote new ideas. Integrating the design and construction expertise has been shown to improve constructability and other project qualities. The case study interviews asked the participants to rate the extent that the design and construction were integrated on the project and the extent in which multiple firms on the project worked together as a team. Figures 19a and 19b show the relationships between project team integration and innovation using the interview participant ratings of integration and the researcher ratings of integration, respectively. The data reveal moderate, positive relationships between integration and innovation (R^2 = 0.273 and 0.52).

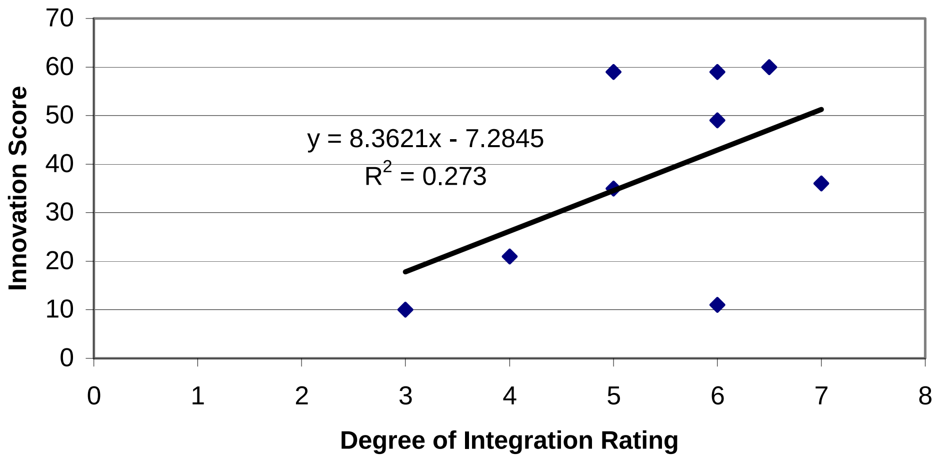


Figure 19a. Impact of Project Team Integration on Innovation – Participant Ratings (Case Study Projects)

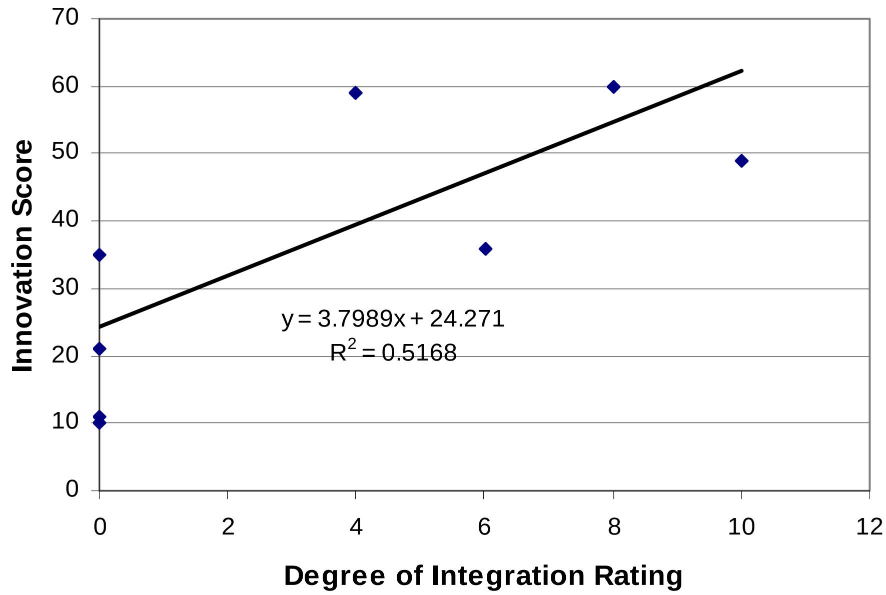


Figure 19b. Impact of Project Team Integration on Innovation – Researcher Ratings (Case Study Projects)

5.2.5 Communication

The literature identifies communication between project participants as a factor that affects innovation. Open communication channels over which there is cross-discipline, multi-lateral (i.e., not just top-down) communication allows for sharing of project information and ideas. In addition, when the communication is encouraged, and proactive rather than reactive, a climate exists which supports collaboration and working as a team. The case study interviews explored these factors by asking to what extent was the communication on the project: open, cross-disciplined, unilateral, and encouraged. The responses to these four questions were used to create an aggregate communication rating.

The relationship between communication and innovation using the ratings provided by the interview participants is shown in Figure 20a. It is interesting to note the negative correlation between communication and innovation which, if accurate, would indicate that as communication improved, innovation decreased. This is opposite of what is described in innovation literature and the results of the benchmarking survey. Using the researcher ratings of communication based on the information gathered in the case study interviews, a different relationship with innovation is seen (see Figure 20b). The figure shows that as communication improves, so does innovation ($R^2 = 0.63$).

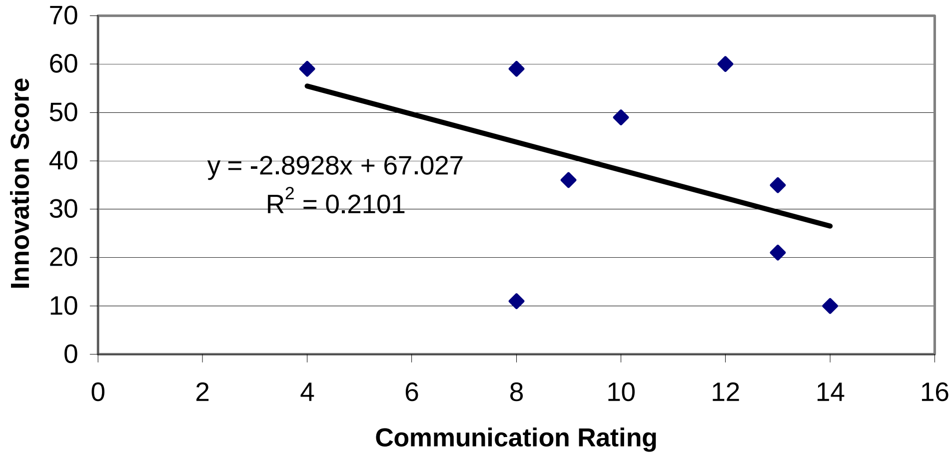


Figure 20a. Impact of Communication on Innovation – Participant Ratings (Case Study Projects)

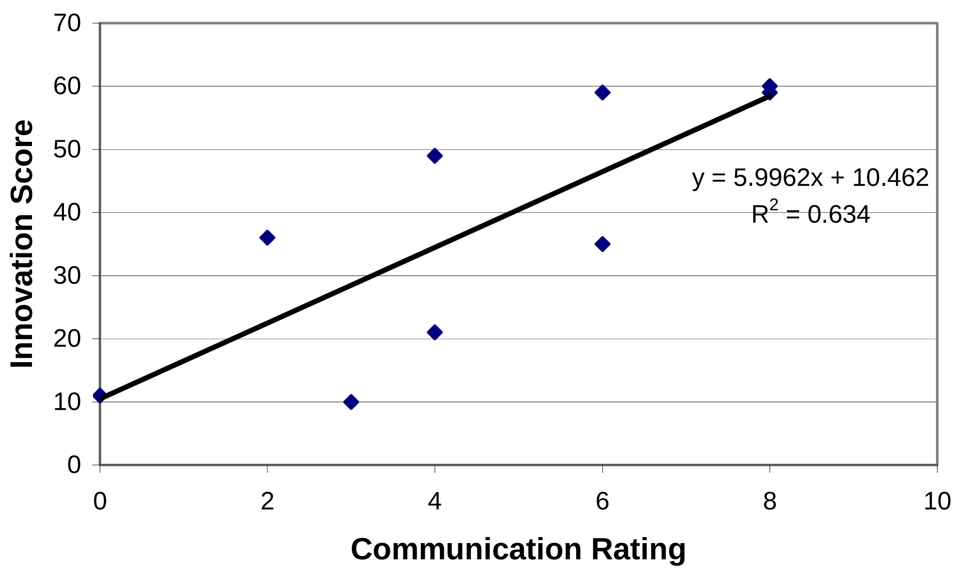


Figure 20b. Impact of Communication on Innovation – Researcher Ratings (Case Study Projects)

5.2.6 Lessons Learned/Knowledge Management

The impact of a lessons learned/knowledge management process on innovation was investigated as well. Capturing, organizing, and disseminating lessons learned on one project throughout the firm is a way to diffuse information about innovations and information that can lead to innovations. As discussed previously, diffusion must occur in order to have innovation. The research investigated the impact of a lessons learned/knowledge management system on innovation by asking the following questions:

- Does your firm have formal mechanisms to **capture lessons learned** and to what extent are the mechanisms implemented?
- Does your firm have formal mechanisms to **disseminate lessons learned** and to what extent are the mechanisms implemented?
- Does your firm have formal mechanisms to **disseminate innovations** and to what extent are the mechanisms implemented?
- Does your firm **implement** lessons learned on future/subsequent projects and to what extent are the lessons learned implemented?

The responses to the questions were used to determine an aggregate lessons learned rating for each case study project. Figure 21a shows the results of this analysis using the ratings provided by the interview participants. While the figure shows a positive relationship (i.e., as the extent to which a lessons learned process is implemented and used increases, innovation also increases), the relationship is not strong within the case study project data ($R^2 = 0.19$). Figure 21b shows a similar relationship using the researcher ratings. Using the researcher ratings, a stronger positive relationship is seen between lessons learned and innovation ($R^2 = 0.79$).

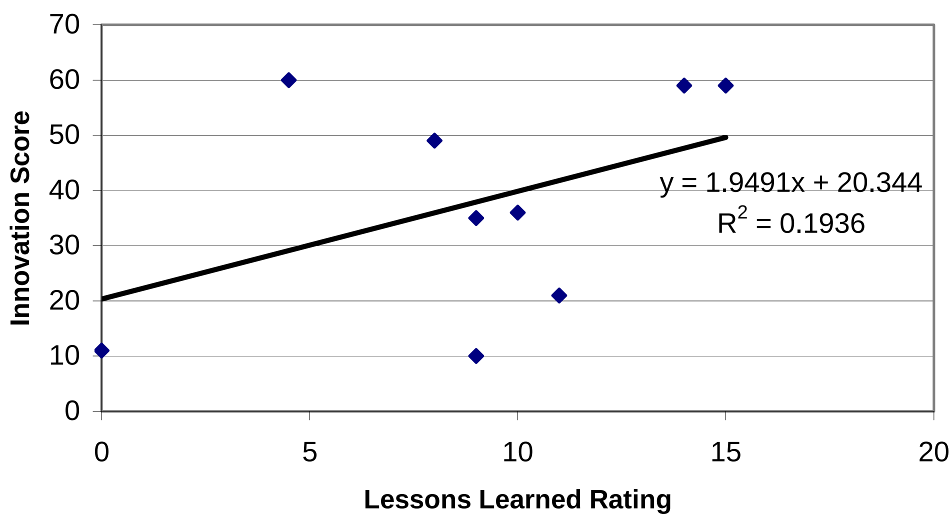


Figure 21a. Impact of Lessons Learned Process on Innovation – Participant Ratings (Case Study Projects)

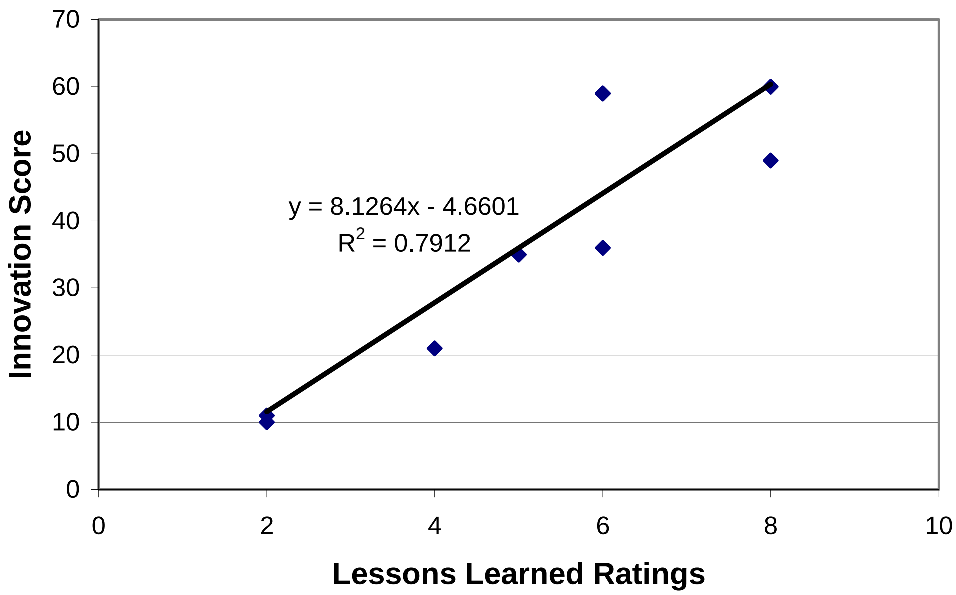


Figure 21b. Impact of Lessons Learned Process on Innovation – Researcher Ratings (Case Study Projects)

5.2.7 Upper Management Support

The support of upper management within a firm significantly impacts many aspects of projects. In the benchmarking survey, upper management support was most commonly identified factor that enables innovation. Support can be provided in many different ways. In the case study interviews, upper management support was investigated through the following questions:

- To what extent is innovation part of your firm's organizational strategy?
- To what extent is innovation part of your firm's mission statement?
- To what extent is innovation part of your firm's business plan?
- To what extent is innovation part of your firm's budget?
- To what extent does your firm hold innovation meetings?
- To what extent were employees allotted time to explore new ideas?
- 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 innovation on the project using the participant ratings is shown in Figure 22a. The figure shows a weak but positive correlation between upper management support and innovation (R^2 = 0.17). Using the researcher ratings of upper management support, the correlation improves (see Figure 22b). The analysis reveals a moderate to strong relationship between upper management support and innovation for the case study projects using the researcher ratings (R^2 = 0.79).

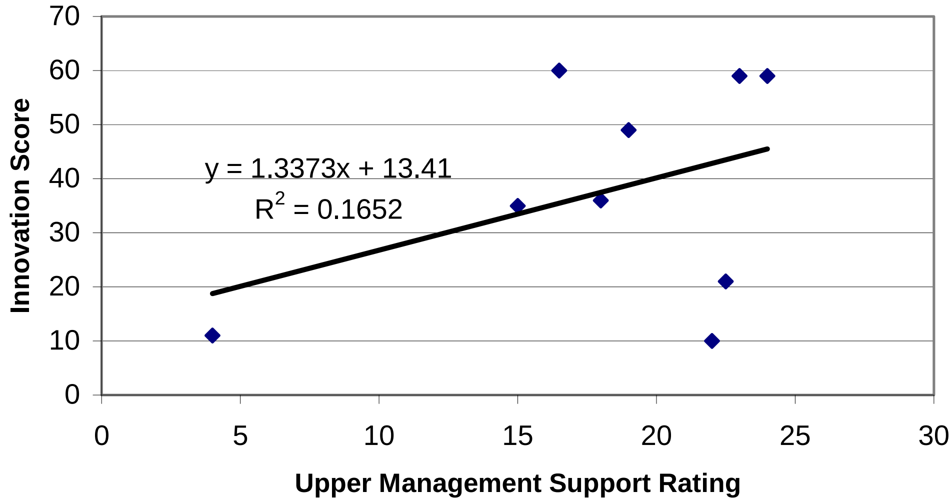


Figure 22a. Impact of Upper Management Support on Innovation – Participant Ratings (Case Study Projects)

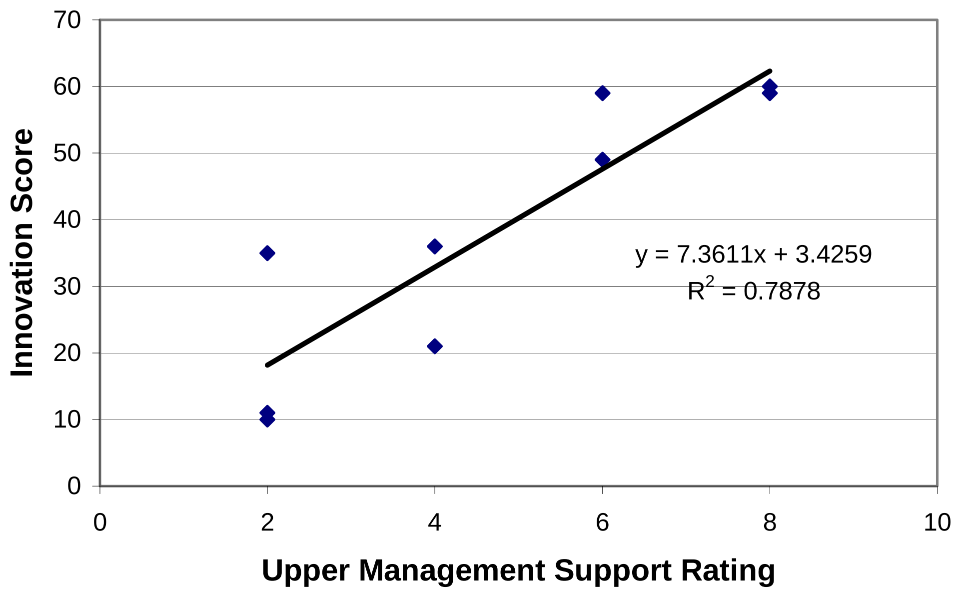


Figure 22b. Impact of Upper Management Support on Innovation – Researcher Ratings (Case Study Projects)

5.2.8 Research and Development

Research and development of new concepts, technologies, and processes can be instrumental in, and is often a requirement for, the innovation process. Formal R&D programs within engineering and construction firms are not common, especially within small- and medium-sized firms. It is perhaps the case, however, that R&D occurs at a more informal level where those involved in the innovative change, and perhaps along with the innovation champion, try out and develop the new idea on different occasions. The extent to which this occurs can impact success at innovation. The case study interviews used four questions to assess R&D:

- To what extent does your firm perform R&D?
- To what extent does your firm include R&D in project budgets?
- To what extent was there time allowed for R&D on this project?
- To what extent was R&D supported by your firm for this project?

Similar to the other leading indicators, aggregate ratings were calculated based on the responses to all four of the questions. Figures 23a and 23b show the relationships between R&D and innovation using the participant ratings and the research team ratings, respectively. Both figures show a positive relationship (i.e., as R&D increases, innovation also increases). There is a weak relationship using the participant ratings ($R^2 = 0.01$), but a very strong relationship using the researcher ratings ($R^2 = 0.89$).

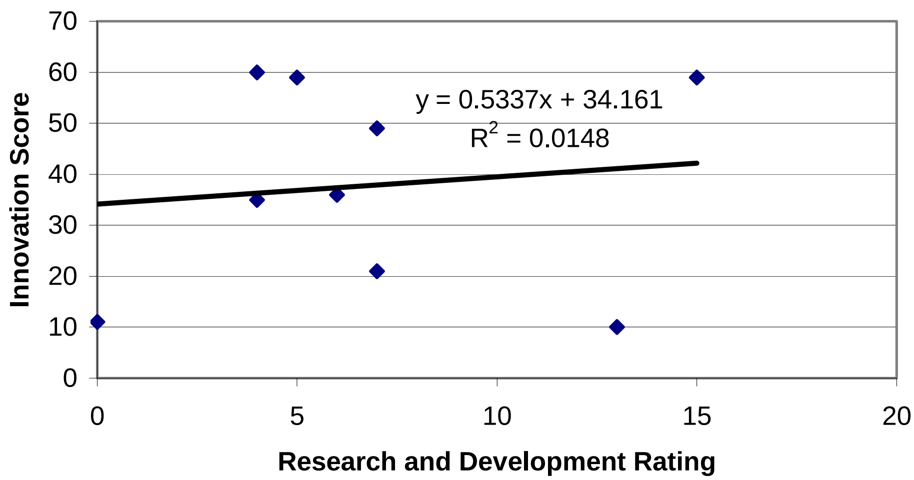


Figure 23a. Impact of R&D on Innovation – Participant Ratings (Case Study Projects)

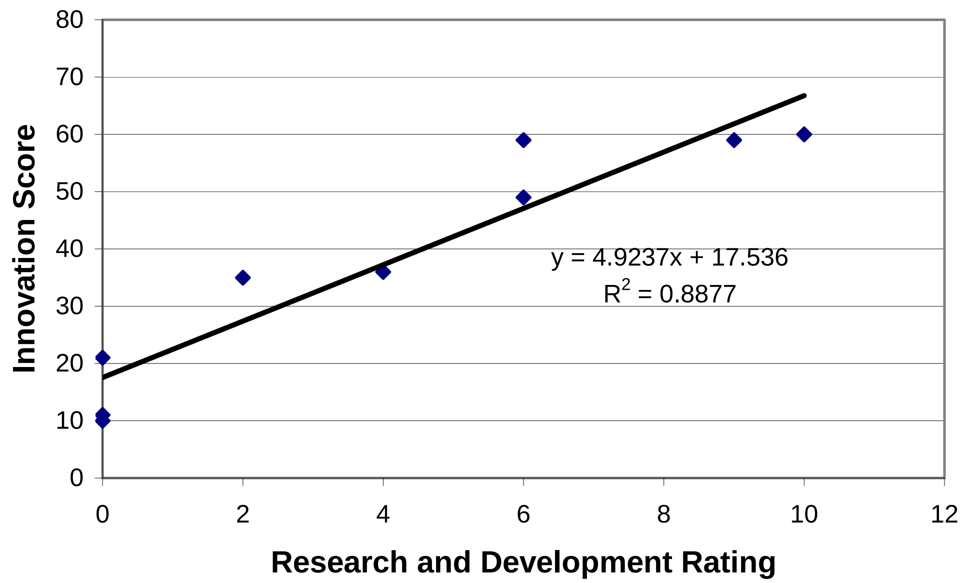


Figure 23b. Impact of R&D on Innovation – Researcher Ratings (Case Study Projects)

5.2.9 Employee Recognition

Recognizing employees for their ingenuity and motivation for positive change on projects is a way of encouraging innovation to occur. This recognition can be provided in many different ways (e.g., letter of appreciation, award, promotion, etc.), and publicly or in private. Recognition of employees was identified by the Industry Advisory Board as an enabler of innovation. The research assessed the impact of recognition on innovation through three questions asked during the case study interviews:

- Does your firm have formal mechanisms to recognize the contributions of individuals and to what extent are the mechanisms implemented?
- Does your firm have formal mechanisms to recognize the contributions of teams and to what extent are the mechanisms implemented?
- Does your firm have formal mechanisms to recognize the contributions of subcontractors and to what extent are the mechanisms implemented?

Figure 24 shows the relationship between the aggregate responses to these questions and innovation on the projects. As seen in the figure, the data does not reveal the presence of a correlation between employee recognition and innovation (R^2 = 0.006).

Insufficient additional information was gained in the case study interviews for the research team to develop its own reliable rating of employee recognition on the case study projects. Therefore, no relationship between employee recognition and innovation using researcher ratings was investigated.

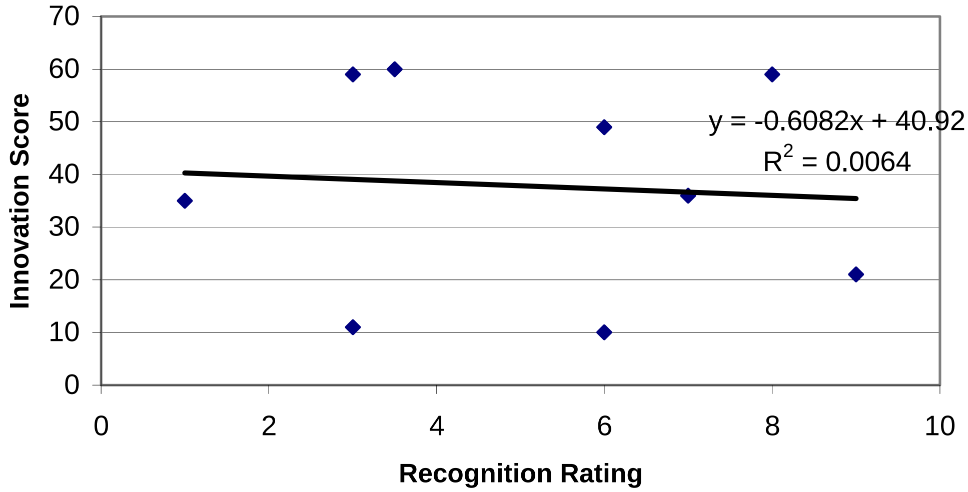


Figure 24. Impact of Employee Recognition on Innovation – Participant Ratings (Case Study Projects)

5.2.10 Organizational Climate

The culture of an organization with respect to innovation was identified in the literature as an impact to innovation. 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. However, 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.

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 employee acts. Examples of factors that impact organizational climate with respect to innovation include upper management's emphasis on innovation and whether formal recognition is given to those employees who innovate. The case studies and benchmarking survey data gathered allowed for assessing the impact of organizational climate on innovation. To evaluate how an organization's climate impacts the level of innovation, an aggregate organizational climate score was created in a manner similar to that used for determining the innovation score.

Using the case studies, 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 using the participant ratings. Figure 25a shows the relationship between organizational climate and innovation using the participant ratings. While the data shows a positive correlation between organizational climate and innovation, it is a very weak relationship (R^2 = 0.05). A similar organizational climate rating was created using the research team ratings and compared to the innovation scores of the projects (see Figure 25b). Using the researcher ratings, the data show a very strong positive correlation between organizational climate and innovation (R^2 = 0.88).

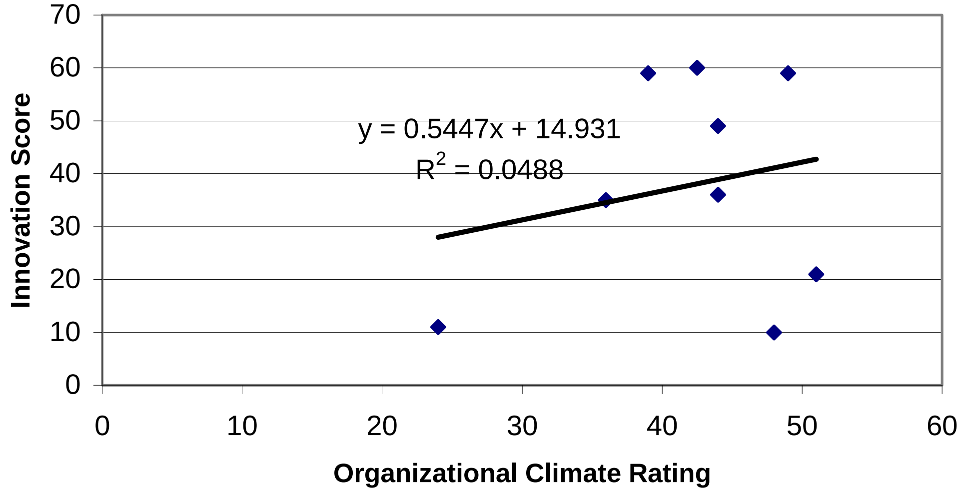


Figure 25a. Impact of Organizational Climate on Innovation – Participant Ratings (Case Study Projects)

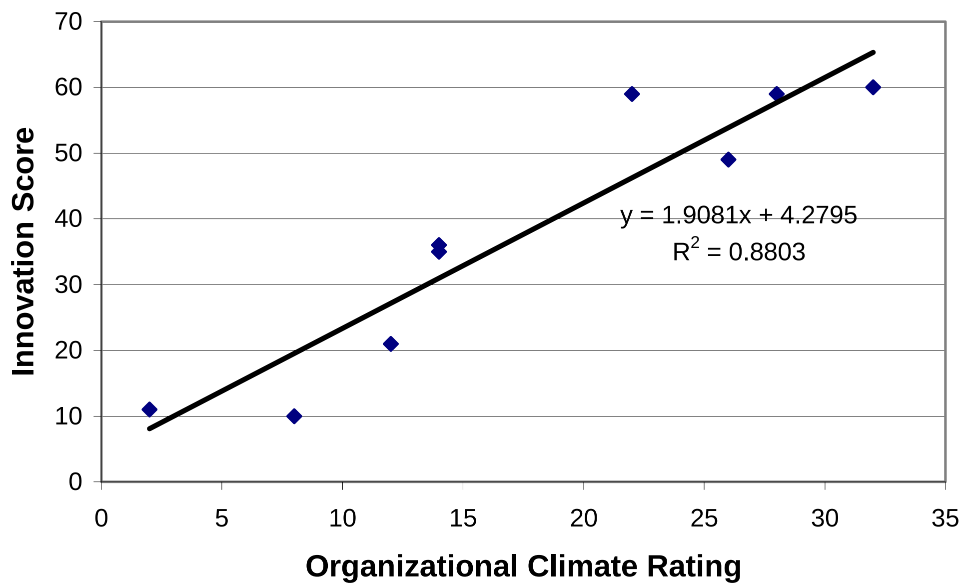


Figure 25b. Impact of Organizational Climate on Innovation – Researcher Ratings (Case Study Projects)

A similar process was used to correlate organizational climate and innovation using the benchmarking survey data. The following four benchmarking survey questions were selected to develop the organizational climate score:

- To what extent is innovation linked to the overall organizational strategy of your firm?
- To what extent are your firm's innovation experience and successes used to market your firm?
- For those employees who develop new products, technologies, or processes for your firm, to what extent are the employees supported, recognized, and rewarded for their work on the innovations?
- To what extent does your firm emphasize (value) innovation on projects or within the firm?

Similar to the innovation score, each of these questions was answered using a Likert scale, and the responses were given points from 0 – 4 depending on the response rating. An organizational climate score was calculated for each firm by summing the points received on the four questions and then normalizing to a scale of 1 – 10. A high organizational climate score represents a firm that has a climate which is very conducive to innovation; firms with a low score have organizational climates that are not conducive to innovation. The distribution of organizational climate scores using the benchmarking survey data is shown in Figure 26. The range of organizational climate scores extends from a low of zero to a high of ten with a mean score of 4.6 (median = 4.4).

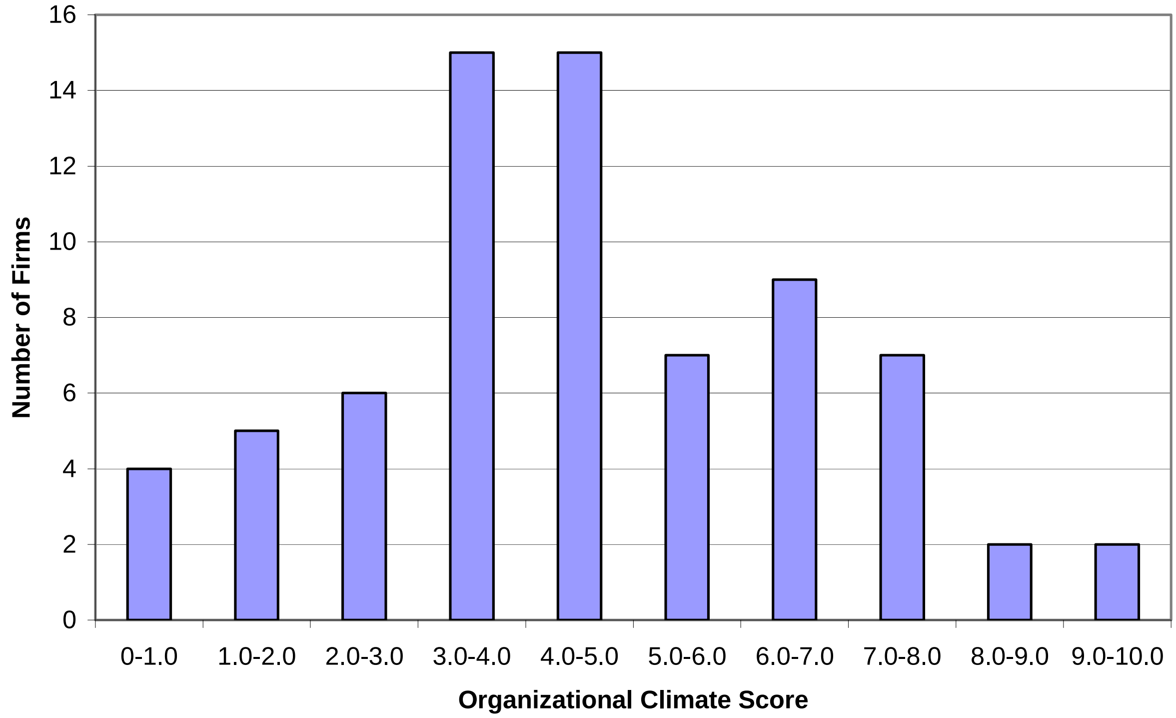


Figure 26. Distribution of Organizational Climate Scores (Benchmarking Survey)

Figure 27 shows the relationship between organizational climate score and innovation score for the firms responding to the benchmarking survey. The data are scattered, however there is a slight indication of a positive correlation between the scores (linear regression, $R^2 = 0.42$), i.e. when the organizational climate score increases, the innovation score also increases. This trend is expected based on the impact that organizational climate has on the level of innovation that occurs in a firm.

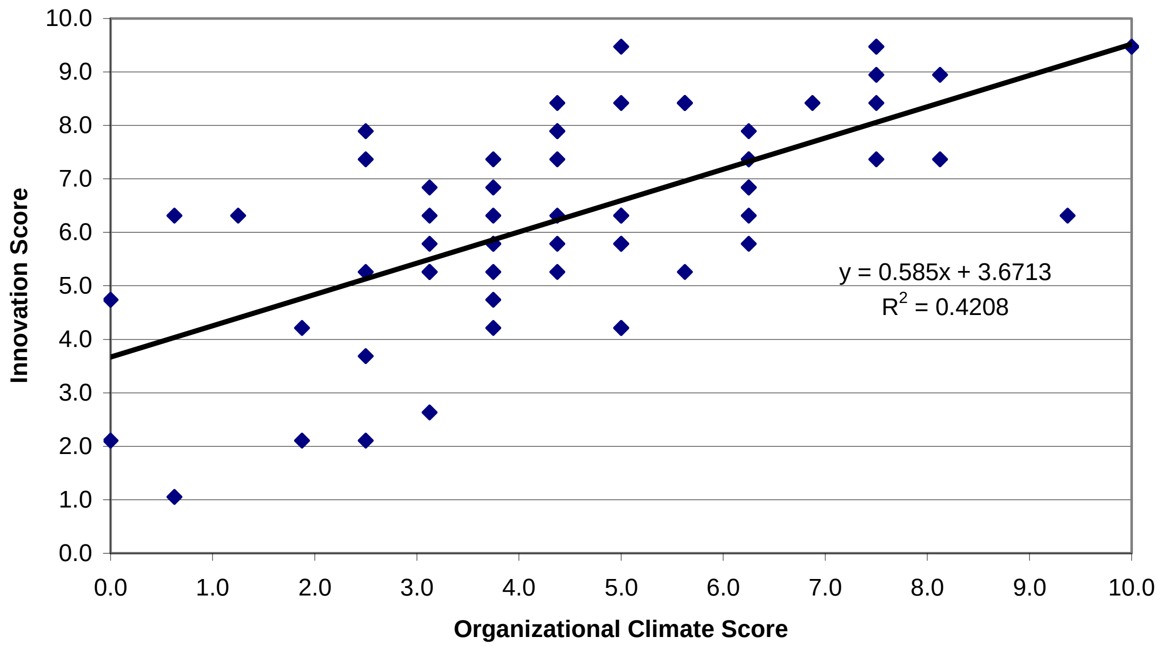


Figure 27. Impact of Organizational Climate on Innovation (Benchmarking Survey)

5.2.11 Organizational Structure

As described in the Literature Review section of this report, the literature reveals that organizational structure also can have an impact on innovation. There is key evidence that growing companies which promote innovation in their firm are more successful (Steel 2001). 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. An organization's structure should, however, not be overly restrictive, complicated, or multi-layered, and stifle opportunities for developing and implementing new ideas. In a manner similar to organizational climate, to gauge the impact of an organizations structure on innovation, organizational structure scores were calculated using aggregates of the case study and benchmarking survey data.

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 takes 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 using the participant ratings. Figure 28a shows the relationship between organizational structure and innovation using the participant ratings. A weak, but positive, relationship (R^2 = 0.14) between organizational structure and innovation is seen in the case study projects based on the participant ratings. A similar organizational structure rating was created using the research team ratings and compared to the innovation scores of the projects (see Figure 28b). Using the researcher ratings, the data show a much stronger positive correlation between organizational structure and innovation ($R^2 = 0.90$).

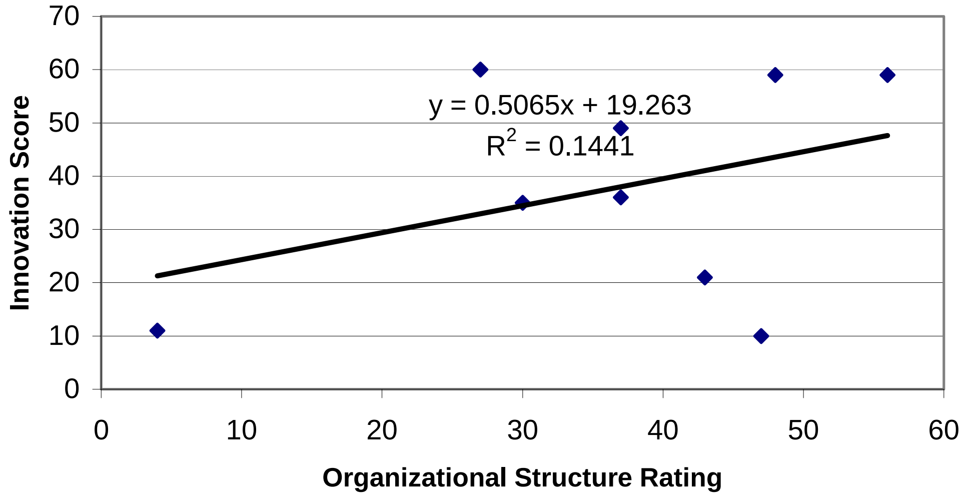


Figure 28a. Impact of Organizational Structure on Innovation – Participant Ratings (Case Study Projects)

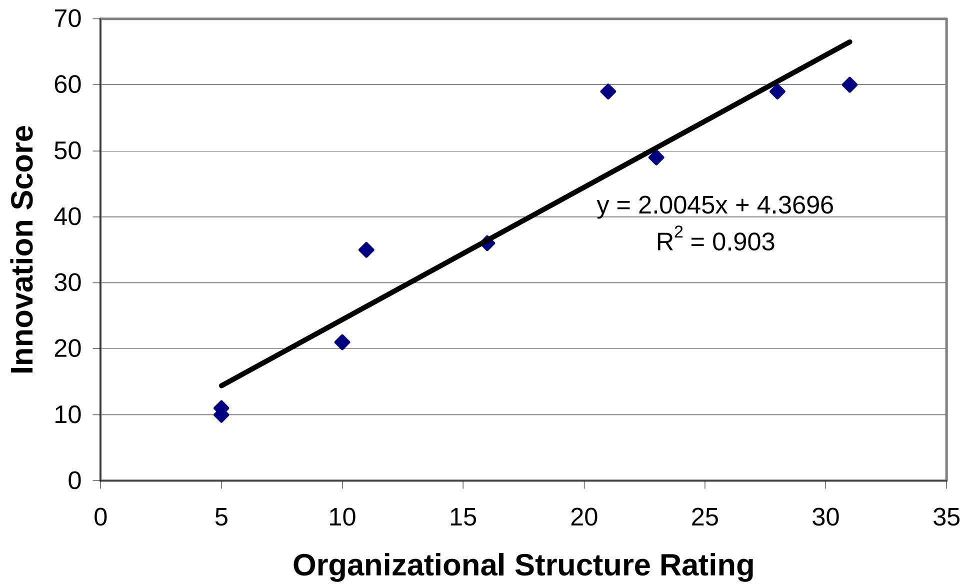


Figure 28b. Impact of Organizational Structure on Innovation – Researcher Ratings (Case Study Projects)

A similar process was used to analyze the benchmarking survey data. Seven benchmarking survey questions were used to create an aggregate organizational structure score:

- Does your firm set aside a portion of its annual budget for the development and implementation of new products, technologies, or processes? If so, what percentage is budgeted for innovation activities?
- Are there employees within your firm who are responsible for seeking out, developing, and implementing new products, technologies, or processes? If so, how many employees, and what percentage of their work is devoted to this responsibility?
- Does your firm have a formal plan for developing and implementing new products, technologies, or processes (i.e., an Innovation Plan)?
- To what extent is innovation linked to the overall organizational strategy of your firm?
- To what extent are your firm's innovation experience and successes used to market your firm?
- To what extent are there formal mechanisms in your firm to capture and share lessons learned associated with the innovations that occur in your firm?
- Please rate you firm’s ability to measure and track innovations.

Similar to the other calculated scores, the responses were given points based on a 0-4 scale, or 5/0 for Yes/No questions. An organizational structure score was calculated for each firm by summing the points received on the seven questions and then normalizing to a scale of 1 – 10. A high organizational structure score represents a firm that has a structure which is very conducive to innovation; firms with a low score have organizational structures that are not favorable to innovation. The distribution of organizational structure scores from the benchmarking survey is shown in Figure 29. The range of organizational structure scores extend from a low of 0.97 to a high of 9.0 with a mean score of 3.8 (median = 3.4).

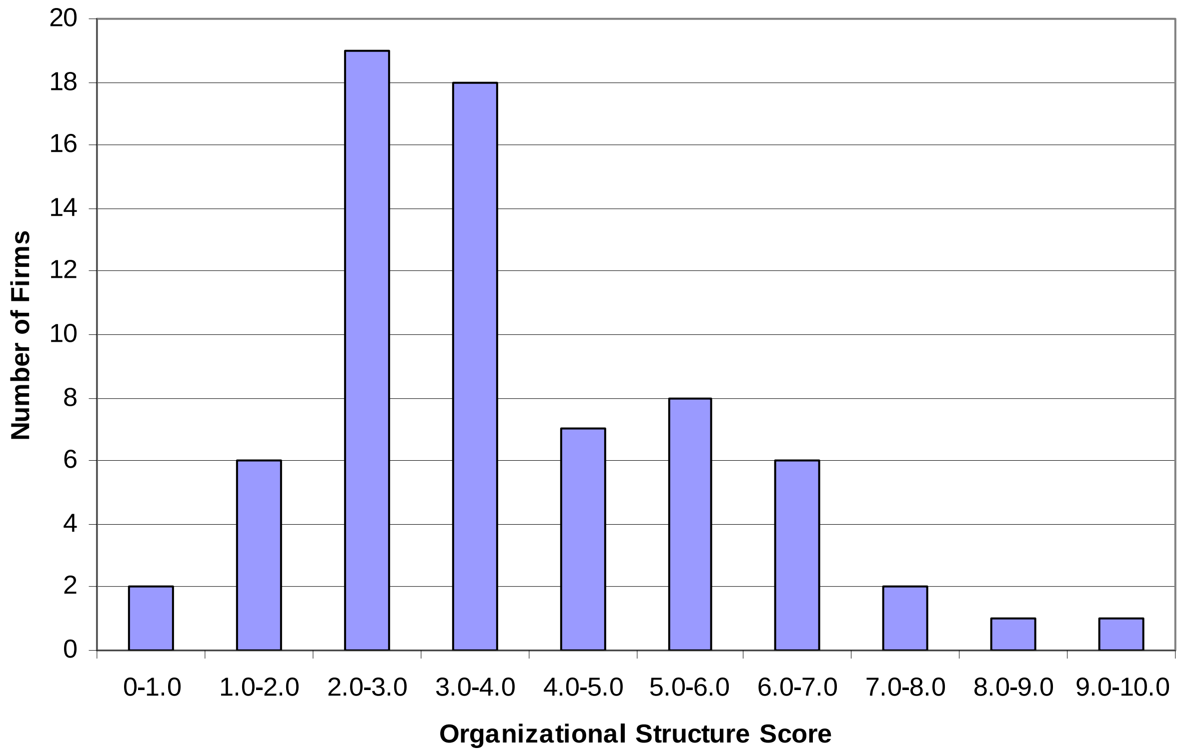


Figure 29. Distribution of Organizational Structure Scores (Benchmarking Survey)

The relationship between organizational structure score and innovation score for the firms in the benchmarking survey is shown in Figure 30. There does not appear to be a relationship between organizational structure and innovation score for the firms that responded to the survey (linear regression, R^2 = 0.0007).

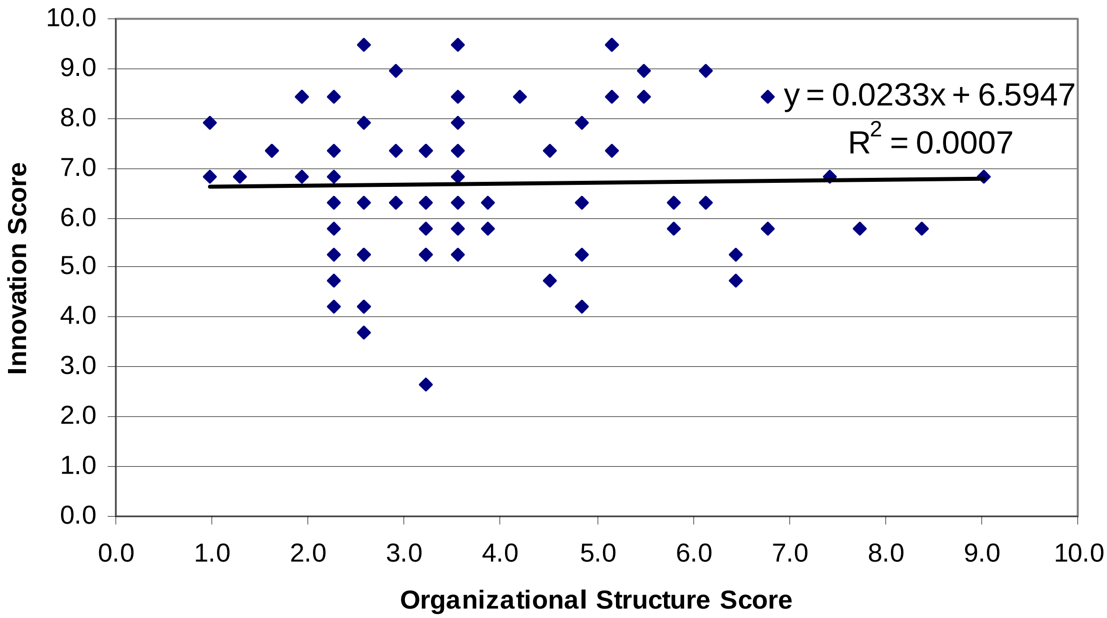


Figure 30. Impact of Organizational Structure on Innovation (Benchmarking Survey)

5.2.12 Work Type

The case studies solicited input about whether the project was a new ("greenfield") project or a renovation/maintenance project. As shown in Table 1, six of the ten case study projects (60%) were new projects and the remaining were renovation projects. Figure 31 shows the average innovation scores for the new and the renovation case study projects. Innovation was found to be greater on the new projects in the case study sample.

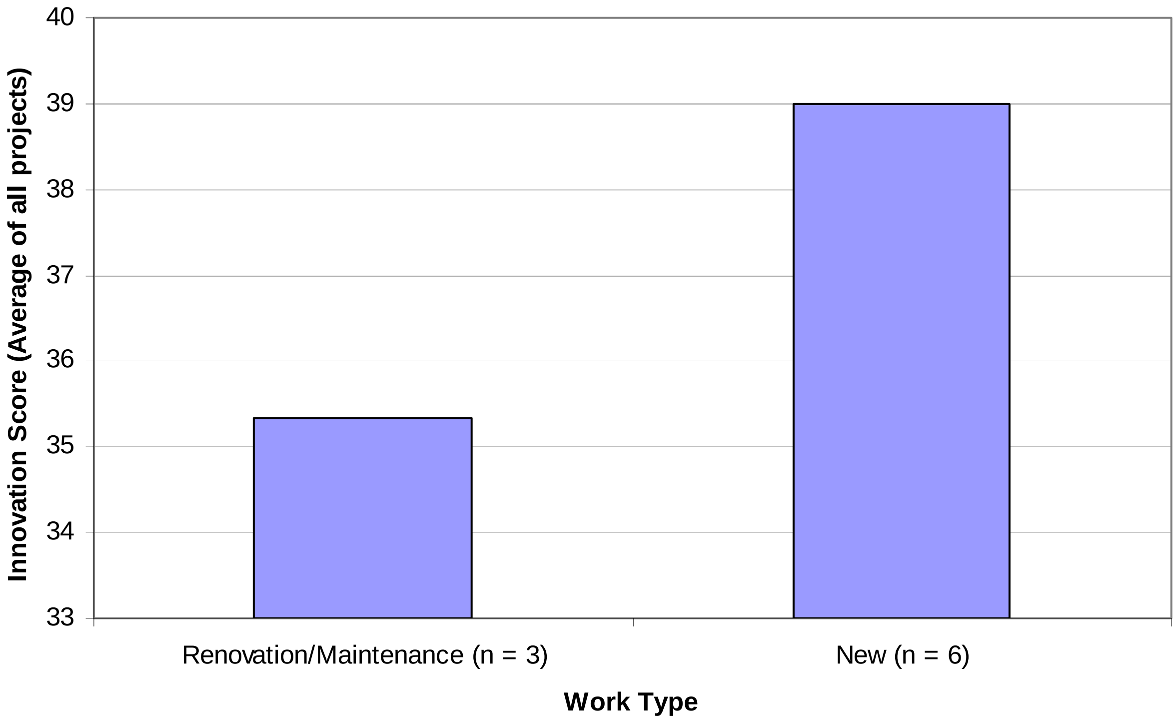


Figure 31. Impact of Work Type on Innovation (Case Study Projects)

In the benchmarking survey, respondents were asked to indicate the percentage of work which their firms conduct which is new work and which is renovation work. Average innovation scores were calculated for firms that have over 60% of their work as new work. A similar calculation was done for firms that have greater than 60% of their work as renovation work. For those firms that primarily do new work, their innovation score was 6.6, compared to 6.1 for those firms who primarily do renovation work. A higher innovation score indicates greater innovation. This result supports the findings from the case study project analyses described above.

5.2.13 Project Size

The case study data was also analyzed to determine if there was a relationship between project size and innovation. The size of each project was based on the approximate dollar value of the project. Small projects were categorized as those valued at less than $20 million. Medium projects are those between $20 million and $100 million, and projects greater than $100 million were categorized as large projects. Figure 32 shows the innovation scores for the projects based on size. Innovation score was highest for large projects.

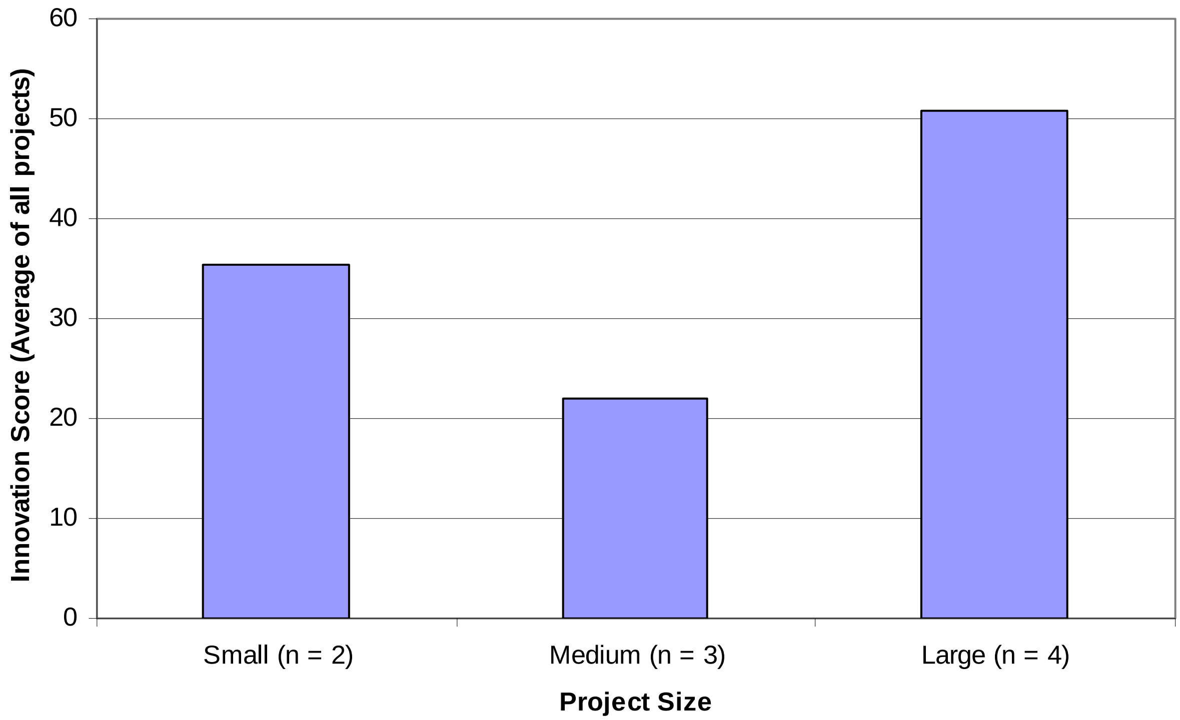


Figure 32. Impact of Project Size on Innovation (Case Study Projects)

5.2.14 Firm Size

The benchmarking survey provided data to investigate the impact of firm size on innovation. Figure 33 shows a plot of the innovation scores versus the annual revenue of the firm (in $ millions). As can be seen from the figure, there appears to be no relationship between annual revenue and innovation score for the firms in the study sample. The size of the firm, based on annual revenue, does not appear to impact the level of innovation that occurs on the projects built by the firm. Good ideas can come from many different places. While large firms may have more resources to devote to R&D of the new ideas, the structure and procedures needed to run a large firm may impact diffusion of new ideas. Large firms with significant resources may also be more risk averse since they “have something to lose”.

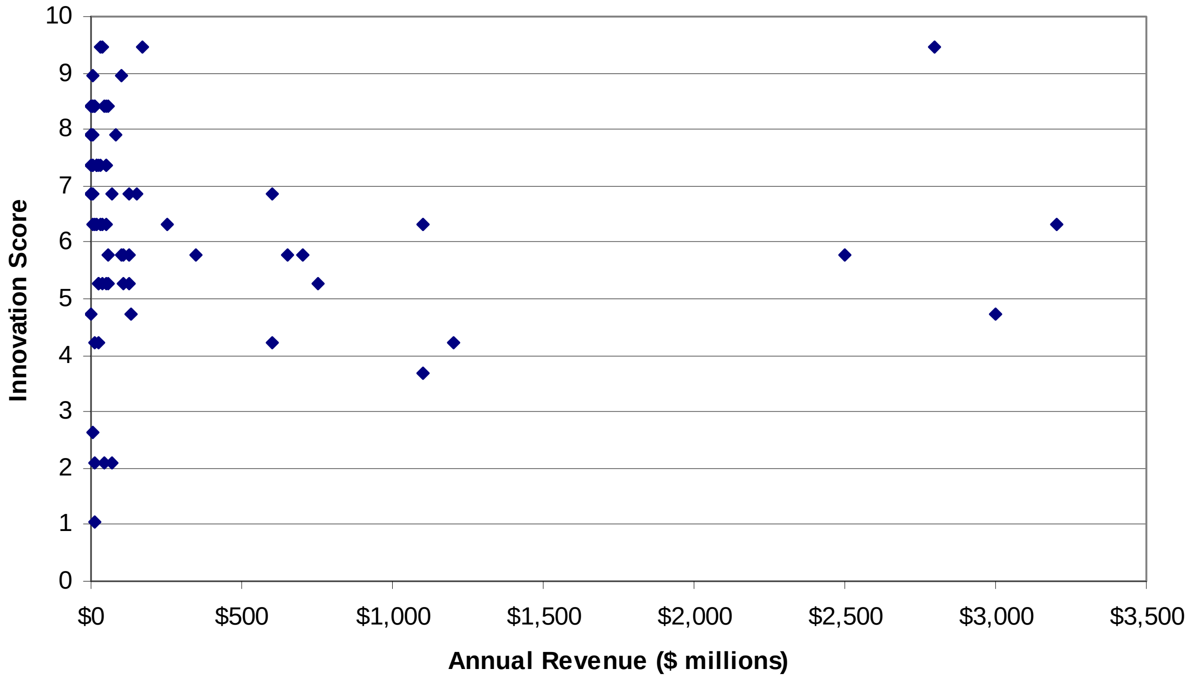


Figure 33. Impact of Firm Size on Innovation (Benchmarking Survey)

5.2.15 Project Delivery Method

The contracting method used to delivery a project can impact the extent to which project team members collaborate, communicate, and share information to the benefit of innovation on the project. In addition, some project delivery methods allow for integration of discipline expertise earlier in the project lifecycle which can have a positive impact on innovation. Figure 34a shows a comparison of project delivery methods used on a project with respect to the innovation score for the case study projects. Innovation scores were higher on average for the design-build projects in the study sample. The nature of design-build projects which integrate the project team disciplines enables the generation and implementation of innovative ideas.

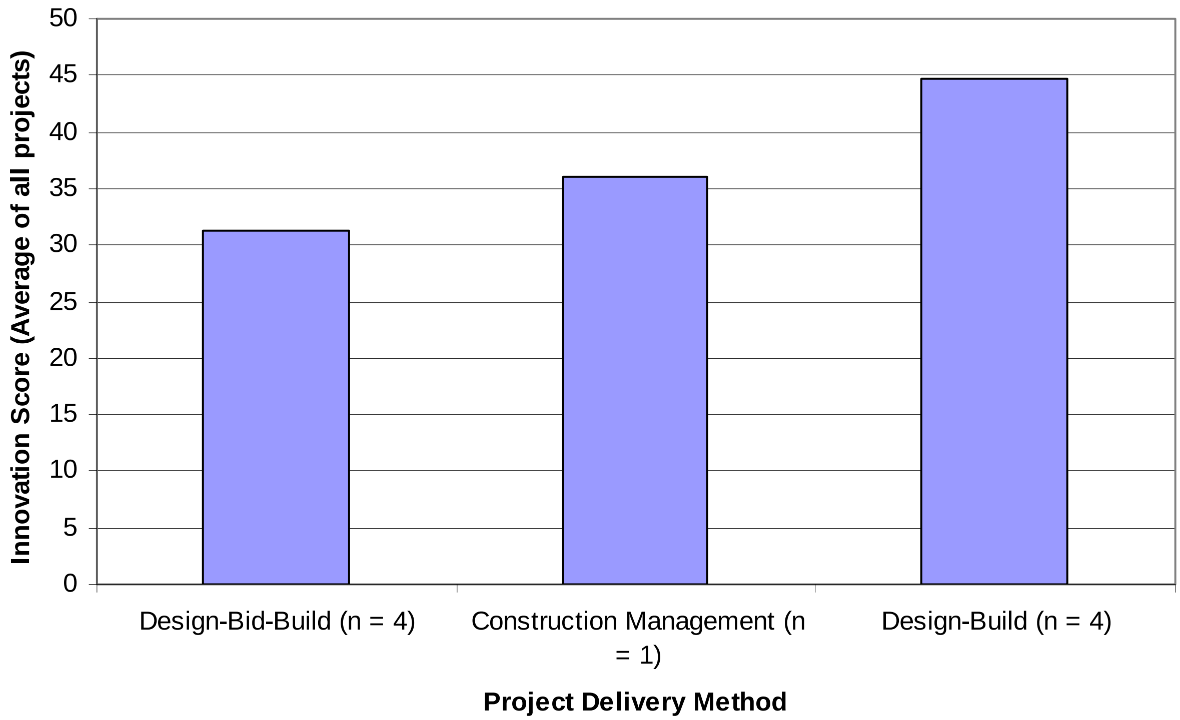


Figure 34a. Impact of Project Delivery Method on Innovation (Case Study Projects)

In the benchmarking survey, responses to the question regarding the firm's ability to innovate within various project delivery methods indicate that those methods which integrate design and construction expertise, such as Design-Build and CM/GC, tend to allow firms to innovate at a greater level. This relationship was also tested using the benchmarking innovation score. Using the demographics question which asked for the approximate percentage distribution of project delivery methods in which their firm participates, the responding firms were designated as DBB, DB, CM/GC, CM @ Risk, or CM based on the amount of work which they perform within each delivery method. A firm was classified as delivering primarily within one delivery method if the firm delivers at least 75% of projects within one specific delivery type. For example, a firm delivering at least 75% of their work via DBB was classified as a DBB firm. Firms which do not have at least 75% of their work within one delivery method were omitted from this particular analysis. The results from this categorization with respect to innovation score are shown in Figure 34b. Innovation success score was the highest for CM/GC (7.5), followed by DBB (6.3), DB (5.7), and CM @ Risk (5.3). No firms performed more than 75 percent of their work using the CM delivery method.

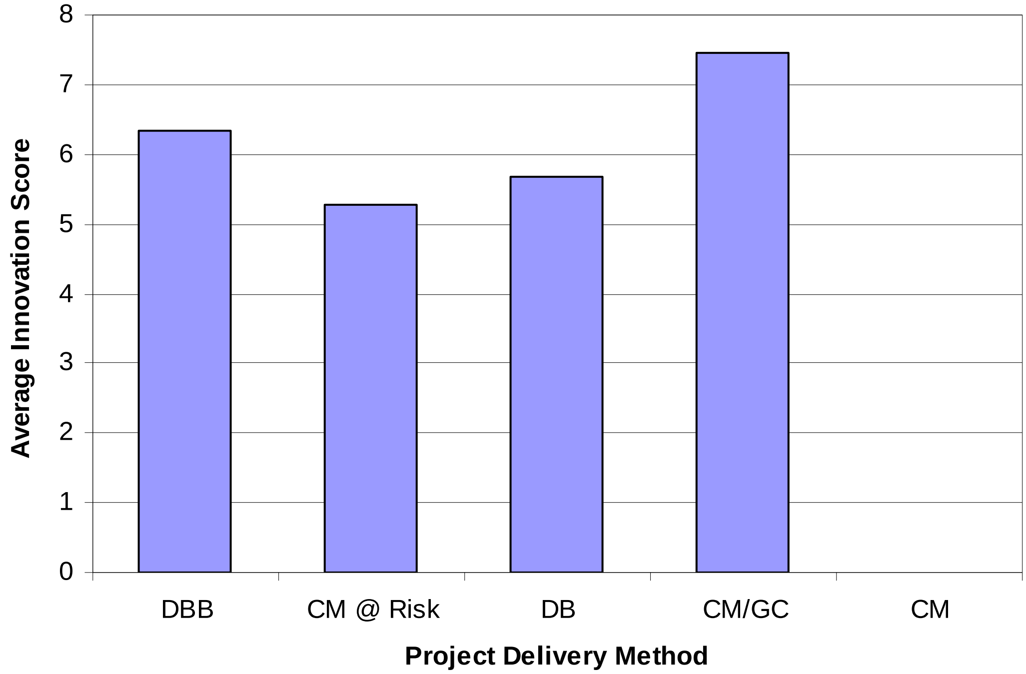


Figure 34b. Impact of Project Delivery Method on Innovation (Benchmarking Survey)

5.3 Predicting and Measuring Innovation

The analysis described above indicates that there are many factors that affect innovation on a project. These include: owner influence, presence of an innovation champion, project team collaboration, degree of project team integration, communication, lessons learned/knowledge management, upper management support, research and development, and employee recognition. Each of these factors impacts innovation to some extent on its own. Measuring the magnitude and 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 on a project.

When considered together, the factors can be used to more accurately predict innovation. This is illustrated in Figure 35 which shows the relationship between the combined leading indicator scores (the sum of all of the ratings for the different leading indicators) based on the researcher ratings and innovation on the projects. The data reveals a very strong, positive correlation between the indicators and innovation ($R^2 = 0.91$).

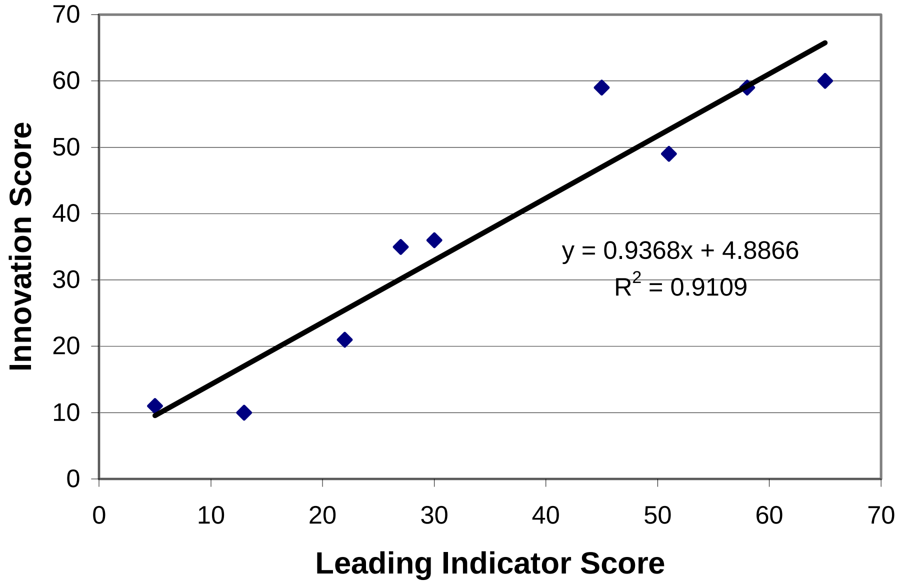


Figure 35. Impact of Leading Indicators on Innovation – Researcher Ratings (Case Study Projects)

Taking the study findings from research to practice requires recognition of design and construction practices and the qualities and 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 impacted 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 below and are included in the Innovation Manual of Practice. For some factors a simple Yes/No response is appropriate, whereas for other factors a rating is required to indicate level or magnitude (such as a 1-5 rating).

- Owner Influence
    - The extent to which innovation is an objective of the owner.
    - The level of support (monetary, time, encouragement, etc.) given by the owner to innovation on the project.
- Innovation Champion
    - The presence of a champion, sponsor, or initiator for an innovation, or for innovation within a project or firm.
    - The 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 all project team members in project meetings, constructability reviews, Value Engineering, and other quality control efforts.
- Project Team Integration
    - Use of an integrated project delivery method (e.g., design-build).
    - The extent to which multiple project team members worked as a team.
    - The extent to which different disciplines are involved in each project function.
    - Whether the design and construction phases overlap.
    - Diversity of the project team.
- Communication
    - The extent to which communication channels are open.
    - The extent to which communication is cross-discipline.
    - The extent to which communication is encouraged and proactive.
    - The extent to which communication is not unilateral.
    - The extent of face-to-face communication.
- Lessons Learned/Knowledge Management
    - The presence of a lessons learned process and program.
    - The extent to which lessons learned are captured and disseminated.
    - The 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.
    - The extent to which innovations are used in marketing the company.
    - The level of resources (monetary, time, etc.) devoted to innovation.
    - The extent to which R&D is supported by upper management.
- Research and Development
    - The extent to which the firm performs R&D on potential new products, processes, and systems.
    - The presence of an R&D budget.
    - The 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.
    - The type and value of the recognition provided.

The leading indicators described above can be categorized into three components of innovation: idea generation, opportunity, and diffusion. Each of these three components needs to be present in order for innovation to occur. Innovation starts with new ideas. In order to have innovation, new ideas need to be generated. In order for the new idea to be realized, there must also be an opportunity to implement the new idea, or the need for a new idea. Opportunity can be created by the need to solve a problem, or the desire to improve cost, schedule, quality, and other project characteristics. Lastly, diffusion of the innovation beyond its initial implementation is needed as well. Without diffusion to other projects and the industry, the new idea simply becomes a solution to a specific problem on a project.

In addition to identifying leading indicators to predict the level and opportunity for innovation, the research exposed lagging indicators that can be used to measure the presence of innovation. These lagging indicators are:

- Change in, and impact of, work products, systems, and processes
- Number of feasible new ideas generated, tested, and implemented
- Amount of new training and continuing education required for employees as a result of changes in their work
- Extent and pace of diffusion to other projects and industry
- Impact on: profit, cost, schedule, safety, quality, market share, and competitiveness

When measuring lagging indicators, it is important to compare the measurement to a benchmarked value to get a sense of the magnitude and extent of change. For example, in order to measure how much change occurred due to the implementation of a new product, an assessment of the initial state before the change is required. Comparison of the ending state to the initial state indicates whether change has occurred.

5.4 Validation

5.4.1 Advisory Board Meetings

Presentation of the preliminary research findings to the CEM Industry Advisory Board, and the final research findings to the combined CEM and CE Industry Advisory Boards elicited comments and input from the board members. The board members confirmed many of the research findings and provided additional insight as to innovation enablers, barriers, and outcomes. A summary of the input from the initial CEM board meeting in fall 2006 is provided below:

- Owners can be both an enabler and a barrier.
    - Owners who choose to use an integrated project delivery method and who promote innovation are enablers.
    - Owners can be a barrier if they have a set cookie-cutter design that they want to have built with little to no modifications or deviations from standard plans. Contractors are limited in what they can do by what is on the drawings.
- R&D might be happening on the job site, but it is often simply iterative problem solving and not considered R&D. Contractors often encounter challenges, do some research to identify methods for confronting the challenge, and implement a plan. R&D is sometimes required to actually build the project.
- Construction firms do transfer innovations from one project to another if applicable to additional projects.
- The board members agreed that the barriers and enablers that identified and quantified in the benchmarking survey seemed appropriate and correctly valued.
- The impact of the owner on the ability of the contractor to innovate might be a very fruitful sub-topic to this study.

The following additional input was provided in the combined CE and CEM Industry Advisory Board meeting in June 2007:

- In order to determine how much innovation (change) has occurred, a benchmark of the current practices and procedures needs to be established.
- In addition to measuring the number of new ideas actually implemented, the number of new ideas generated, tested, and evaluated should be included when measuring innovation. Trying new ideas is part of the innovation process. Measuring attempts at innovation is an indicator of the level of innovation that is occurring.
- Recognition and rewards programs are key components of motivating employees to innovate.
- There needs to be a benefit/driver or innovation will not occur. The innovator must foresee a positive return on investment.
- Peer groups can be used as a means of assessing the extent to which a project or firm is innovative.

The presentation at the CPF Advisory Council meeting in June 2007 generated additional input and suggestions for the research. The following is a summary of the input provided at the meeting:

- Innovation in the construction industry – does it occur?
    - Decreasing productivity indicates that maybe we are not innovating or that we are not innovating in the right way. Change does not equal innovation.
    - GC's like to find a better way, but codes limit their ability to innovate.
    - The construction industry represents "adopters", not innovators.
    - The construction industry is risk averse and will not adopt new technologies because of fear of litigation.
    - Problem solving is not innovation.
- Barriers to innovation:
    - If the "top dog" in a firm is not an innovator, innovation will not occur.
    - Another barrier is the lack of innovative vision of the upper management. Innovation is a top down process in construction where it may be bottom up in other industries. Someone is needed who sets the tone from the top of the project.
    - Employees are not empowered. There is a difference between construction and the "Toyota way".
        - Rewarded employees innovate more.
        - People who are problem solvers tend to work their way up quickly in construction firms; in other industries these people are simply considered to be doing their job.
- Additional innovation metrics:
    - Amount of training required for new hires.
    - How frequently the training changes.
    - Profitability, growth, and awards.
    - Whether the industry recognizes the firm as an innovator.
    - Amount of change.

The input provided by the industry in the advisory board meetings supported the research findings and indicated that the research was on the right track. New ideas presented by the board members were incorporated into the research where appropriate.

5.4.2 Validation Survey

The validation survey aimed at gaining confirmation of the research findings from a larger segment of the construction industry. A total of 21 responses to the validation questionnaire were received (29% response rate). The respondents provided their perspective on the guidelines and practices developed from the study analysis. The questionnaire asked the respondents to rate the impact of different practices and project characteristics on three different aspects of innovation: idea generation, opportunity for implementation of ideas, and diffusion. The practices and project characteristics listed were those identified from the analyses of the benchmarking survey, innovative product survey, and case studies. The respondents were asked to use a 1-5 rating scale as follows: 1 = not at all; 2 = low; 3 = moderate; 4 = significant; and 5 = extreme. Table 4 summarizes the average ratings for each practice and project characteristic.

Table 4. Impact of Practices and Project Characteristics on Innovation (Validation Survey)

Practice/Characteristic	Overall Impact on Innovation	Impact on Innovation Components		
		Idea Generation	Opportunity	Diffusion
Support and Environment within the Firm:				
Upper management support/commitment	4.33		4.06	
Innovation champion	4.06	3.82	4.00	
Innovative visionaries with the firm			3.94	
Work environment	3.71			
Allowing time for creativity/exploration		3.70	3.82	
Employee recognition	3.48	3.60		
Risk tolerant			3.76	
Owner Influence:				
Owner investment/commitment	4.24		4.21	
Owner commitment of resources			4.36	
Innovation as a goal of the owner			4.07	
Owner's innovation vision			4.00	
Project Team Characteristics:				
Strategic project team selection	3.86	3.76		
Diversity of the project team	3.43	3.18		
Integrated functions of project teams	3.67	3.65		
Project delivery method		3.76		
Collaboration/Integration of Disciplines:				
Overlapping phases	3.05	3.07		
Project team collaboration	4.19	4.29		
Centralized project office		3.18		
Communication:				
Communication with a firm	3.86			4.27
Communication among multiple firms	3.71			3.91
Active communication		4.06		
Multilateral communication		3.90	3.41	
Face-to-face communication		3.71		
Research and Development:				
R&D efforts	3.43			
Time allotted for R&D		3.12		
Employees dedicated to R&D		2.94		
R&D budget		2.88		
R&D meetings		2.88		
Knowledge Management:				
Lessons learned system	3.43			3.73
Employee training and education	3.38	3.59		3.71
Project Development Processes:				
Constructability reviews		3.60		
Value Engineering		3.53		

The ratings given by the validation survey participants ranged from 2.88 to 4.36 (mean = 3.70; median = 3.71). The highest ratings were given in the area of owner influence. This supports the findings from the benchmarking survey and case studies that the vision, support, and actions of the owner are key to innovation. Practices and project characteristics related to upper management support were also rated highly. Collaboration of the project team received high ratings as well. The lowest ratings were given to R&D budget, R&D meetings, and having employees dedicated to R&D. All but three of the practices and project characteristics received ratings of at least moderate impact on innovation. Hence, the input provided by the respondents supports the research findings that the identified practices and project characteristics are indicators of innovation on projects.

5.5 Study Limitations and Bias

As with many studies of construction project performance, the selected research methods and data used in the studies can inhibit the generalization of the findings beyond the study sample. Three major limitations present in this study are described below:

- One limitation impacting the study is the data collection process. The benchmarking 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 construction projects and firms in the U.S. In summary, selection of the benchmarking study sample was not random and, therefore, inferences can be made only to the data set. Generalization to the population is speculative.
- A second limitation is associated with the study inferences. The respondent input to the surveys and responses to the case study interviews is observational data and cannot be used to make cause and effect statements. That is, the quality of the data is subject to the perspectives and biases of the research participants. When rating their own projects 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 biases of the participants.
- Another limitation is the small sample size. A major reason for this small sample size was the extensive amount of time and effort it takes to conduct in-depth case studies, and the difficulties encountered in soliciting information from random projects with which there is no pre-established relationship. The researchers relied on the good will of the participants to provide project information and take the time to be interviewed. A larger sample size would have provided greater confidence in the results.

While limitations and biases exist due to the research methods and participant perspectives, confidence in the research results is provided by the multiple research efforts. Together the literature review, benchmarking survey, innovative product survey, and case studies provide support to the research findings. In addition, the validation efforts confirm the accuracy and relevancy of the study results.

6.0 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 work 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. 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. Industry dynamics is interrelated with competitive advantage and financial success, making it necessary to place strategic change in a competitive context and identify what kinds of changes lead to strategic innovation and ultimately benefits for an organization (Egbu 2001).

6.1 Conclusions

This research study afforded learning about innovation within the context of the construction industry and meeting the six research objectives established for the study. The research activities conducted in this study provide an understanding of the current level and extent of innovation in the construction industry and the factors that impact the innovation process. The literature search exposed many documents that provide a background on innovation and highlight needs for further research. A significant body of literature on innovation in all work industries exists. Researchers have investigated innovation specific to the construction industry. A variety of innovation enablers, barriers, motivating factors, and outcomes are identified in the literature along with descriptions of models of the innovation process in construction that have been developed. Extensive academic study, however, is lacking regarding metrics that can be used to measure innovation performance. Additional research is needed to determine how innovation can be measured and the appropriate metrics to use for measurement. Practical guidelines on how to facilitate and measure innovation in an organization are also needed. The conclusions related to each of the six research objectives are briefly described below.

The interviews and on-line survey in the initial benchmarking activities of the study provided an opportunity to validate the findings of previous research and determine current practices and performance related to innovation. While many feel that innovation in construction is non-existent, the research revealed that it does occur at varying rates (Research Objective 1). While some firms incorporate change at a high rate, others are slow to change. Innovation is taking place on many fronts and commonly in the areas of information technologies, mobile computing devices, construction means and methods, and contracting. Approximately 180 worker-hours are expended on developing and implementing each innovation, and on average almost five months are required to take an innovation from initial concept through implementation.

It was also found (Research Objective 2) that common motivators for innovation are: increasing productivity, reducing cost, staying competitive, and being recognized as a leader in the industry. At the project level, simply solving problems in order to build a project and bring it in on time and within budget is also a motivating factor. These motivating factors are similarly recognized as benefits of innovation.

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. Barriers to innovation (Research Objective 3), however, can, and do, exist at the project, organization, and industry levels. Some of the barriers to innovation include: aversion to risk/change, lack of resources, low return on investment, and strict regulations and codes.

In terms of encouraging innovation and overcoming the barriers to innovation (Research Objective 4), the climate and structure of an organization and project were identified by the project participants as impacts to innovation. 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.

Measuring and tracking innovations (Research Objective 5) was 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 them in this process.

The process of innovation involves different components and activities to generate and develop 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. The research study revealed (Research Objective 6) project and organizational attributes that stimulate and impact these components and which can be used to enhance and measure innovation on projects.

- *Idea Generation*. Innovation starts with an idea. New ideas are conceived and then developed, implemented, and diffused throughout an organization and the industry. The new ideas may be conceived by those working on a project or in a firm, or come from another firm or industry. Generating new ideas is facilitated by:
    - A propensity to be curious and a drive to "find a better way".
    - A mission and surrounding environment conducive to trying and accepting new things (i.e., change) and to always seek to do a better, more efficient job.
    - Continued support and motivation to innovate.
    - Open and proactive communication across project teams and within a firm.
    - Workforce and project team integration and diversity.

- *Opportunity*. Innovation also requires an opportunity or need to develop, implement, and test a new product, process, or system. Opportunities commonly arise in relation to problem solving on a project or in a firm. Project team efforts to solve unique problems expose and elicit innovative solutions. The opportunity to develop, implement, and evaluate the innovative solutions requires the freedom to do so as well as resources (time, funding, labor, equipment, etc.). It is facilitated by sponsors of innovation who eliminate roadblocks and provide support for continued development of the innovation. Opportunity is enhanced by:

  - A project owner and/or firm upper management with a goal to challenge the status quo, expression of the goal, and actions in support of the goal.
  - Commitment of resources and time to explore new ideas.
  - Project development systems and contracts that allow freedom and time to try new ideas and which integrate the different disciplines on a project team (e.g., design-build project delivery method).
  - A "champion" within a firm or project who supports the innovation and "paves the way" for its development and implementation.

- *Diffusion*. Many innovative solutions come about from the need to solve a problem on a project or within a firm. Innovation, however, occurs when that solution is used on subsequent projects or diffused throughout the industry. Lacking diffusion, the innovative process is simply problem solving. Diffusion to other projects and the industry confirms the value of the innovation and leads to positive change. Diffusion is made possible and assisted by:
  - A lessons learned program that captures and disseminates organizational knowledge.
  - Activities for sharing information across project teams and organizations.
  - Working with differing partners (in-house and external) and with different disciplines.
  - Workforce continuing education and training.

The research resulted in the development of guidelines and suggested practices for firms to follow to encourage innovation on projects (Research Objective 6). The guidelines are organized into five main steps: People, Environment, Resources, Systems and Processes, and Monitoring and Management. Guidelines that pertain to People include methods of selecting, training, and organizing employees in such a way that the innovative capacity of the workforce is maximized. Environment consists of those techniques that organizations can utilize to create project settings where innovation may flourish, such as promoting communication amongst the project team, locating employees at a centralized site, and implementing R&D efforts. Resources addresses the monetary, time, and other resources that stimulate and support the innovation process and maintain an innovative climate. Systems and Processes includes those organizational and project management techniques, work processes, and contracting structures that positively influence innovation. Finally, Monitoring and Management contains suggested practices to assess and manage a firm, program, or crew, over time to benefit innovation, such as employee recognition and rewards, knowledge management programs, and a risk tolerant perspective. It is recommended that firms take these steps at the project and firm level to enhance innovation.

6.2 Recommendations

The barriers identified in the research study impact the extent to which innovation occurs. However, all of the identified barriers can be overcome. It is recommended that a firm and the construction industry make the following changes to overcome the barriers and enhance innovation in the industry (Research Objective 4):

- Implement contracting strategies and project delivery processes that promote collaboration, integrate the project team members, and encourage diversity amongst the project team.
- Provide and increase the amount of funding for research and development of new products, processes, and systems.
- Develop models to map the connection between an innovation and project outcomes such as profit, schedule, quality, safety, and sustainability. This will provide practitioners with a tool to understand the implications of the innovations.
- Encourage continued and advanced education and exploration of "the world outside construction".
- Create organizational processes and structures that demonstrate the support of upper management for innovation at both the firm and project levels.
- Recognize employees for their innovative efforts and create environments to stimulate these efforts.
- Develop incentive programs to share the benefits derived from innovation with those who initiate and implement the innovations.
- Conduct thorough risk assessments of new ideas to understand the uncertainty and threats associated with change, and manage the identified risk to bring it to an acceptable level.
- Revise regulations, codes, and bidding procedures to encourage generation of new ideas, collaboration between project team members, and trying new methods.

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. Further research is suggested on the following topics:

Development of models to objectively assess the risk associated with implementing change in a firm and on a project.
There are currently no risk models available that are commonly used for this purpose. Practitioners considering whether to pursue an innovation need a tool to assist them in making appropriate decisions. A risk model could be developed to evaluate the risk associated with an innovation and determine whether to go ahead with the innovation. This would prevent firms from spending excessive time and resources on innovations that are highly speculative and do not have a positive payback. The models should consider the financial, environmental, social, and other affects of the change as well as the uncertainty associated with making change. In addition, consideration should be given to the entire lifecycle of a project and incorporate time as a factor in the model. The research would include a preliminary phase to identify the type and nature of potential risks and a structure for the model. The research would then apply the model in a variety of situations to fine-tune it and verify its accuracy and validity.

Identification 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 of the construction industry which 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. This research should be conducted at both the national and international levels. It should also include an exploration of other industry sectors (e.g., manufacturing, electronics/high tech, etc.) to identify technologies, systems, and processes that can be "mined" for development and use in the construction industry. The research would involve a review of publications and websites that present new products and processes, and interviews of industry practitioners about newly available technologies. A survey of industry practitioners regarding what new technologies they would like to have or problems that they need to solve could provide evidence for highly potential innovations as well.

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. Those innovations which are highly rated could be selected for further study and development. Funding would be provided to develop and test the innovation, diffuse it to the industry, and measure its impact.

Development of a structure and process that better links academic and research institutions with industry to guide and support the movement of new ideas from research to practice.
Some of the innovative products that are being marketed to the industry are initiated through research at academic institutions. The results of research studies sometimes include innovative products and processes which, without further funding after the initial research is complete, exist solely within the research reports written for the studies. Further efforts are needed to set up a network or structure which provides a conduit for moving innovations from academic institutions to the industry. The research could begin with investigating the current process of taking new ideas from research to practice and identifying the related hurdles and roadblocks. Ideas for a new structure and process could be gained through interviews of innovative product manufacturers outside of academia to determine how they have been successful in bringing their products to market. A new structure and process would then be developed which overcomes the barriers, facilitates and provides incentive for moving new ideas to practice, and creates a demand within industry for the results of academic research. Demonstration of the new process could be made through case studies of successful innovations.

Development of models and programs which academic institutions can implement in the educational process to create and support an environment of inquiry and discovery.
The research study presented in this final report highlights the need to have individuals within a firm who are inquisitive and always trying to "find a better way". While this drive may be a personal characteristic based on one's own personality, it could perhaps be exposed and enhanced through directed educational efforts. The intent would be to foster a life-long desire to innovate in new engineers and constructors who are entering the construction industry. The

research would involve assessing the nature and characteristics of current university engineering and construction programs. Educational concepts and programs developed in Colleges of Education could be examined to learn about new educational models that enhance a sense of inquiry and discovery. The research would then aim to develop and implement new delivery methods and content for engineering and construction programs. Dissemination of the new methods and content that proved beneficial would also be included.

Development of a "Leadership in Innovation Rating System" to grade design and construction firms on their innovation capabilities and their success at innovation on projects.
One of the factors identified as a motivator for innovation was being identified as an innovative firm. It is often the case as well that owners prefer working with firms that are believed to be innovators and able to come up with innovative solutions to problems. Beyond personal contact or reference, though, it can be difficult to identify those firms which are more innovative than others. A rating system that can be used to objectively assess the "innovativeness" of a firm could support owners in their selection of a firm based on innovation success. The rating system could also be used for marketing a firm. Such a "Leadership in Innovation Rating System" could be developed by starting with the innovation metrics identified in this research report. The metrics could be combined to create a system which rates a firm or project. A sample of projects could be selected to which the rating system is applied to verify its accuracy. Industry input would also be appropriate to calibrate the system.

Development of a tool to assist design and construction firms to measure innovation.
One of the barriers identified in the research was a lack of tools available to measure innovation. The research study identified metrics for measuring innovation on projects. These metrics could be organized and combined to create a tool for use in measuring the success to which a firm is innovating on its projects. The tool would most likely be an on-line interactive process that evaluates the activities, processes, and structure of a firm. The tool could be applied at the onset of a project as part of project planning or during a project to monitor and manage innovation efforts.

Identification of the characteristics of the innovation adopters in the construction industry.
As presented in the literature review, Rogers (1995) takes an approach to modeling innovation through an understanding of who adopts innovations. The motivation to adopt innovations differs among different groups identified as: innovators, early adopters, early majority, late adopters, and laggards. Innovations are first adopted by the innovators, then by the early adopters, and so forth. 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. Understanding the characteristics of each group would benefit those firms that are developing and marketing their innovations. The ability to directly market innovations to those groups who are most likely or ready to implement the innovations, as opposed to those who are not yet ready to adopt the innovations, can help spread the innovations throughout the industry. This research would benefit the entire industry by helping to increase the rate of industry acceptance and implementation. The research would involve surveying the industry to identify their propensity to change, take on risk, and try

something new. An output of the research could be a report delivered to firms who develop and market innovations that describes the characteristics of each group.

7.0 IMPLEMENTATION PRODUCTS AND DIFFUSION

Products for implementation and dissemination of the research findings were produced as part of the research study. The objective of the collection of products is to provide resources to the construction industry to learn about how to enhance innovation on projects and to assist the industry in their implementation. The products produced from the research are described below.

7.1 Annotated Bibliography

An annotated bibliography was created that provides a list of published references on innovation, on innovation in the construction industry, and on other related topics. The bibliography contains references, with electronic links where available, to journal articles, trade publications, and websites. An abstract of the document is included if available. Also included with the bibliography is a list of five "significant" publications on innovation that are key to understanding innovation in the construction industry. A copy of the bibliography is available on the Pankow Reports webpage under Publications on the SPUR (San Francisco Planning & Urban Research Association) website at: www.spur.org/pankowreports/.

7.2 Innovation Manual of Practice

An Innovation Manual of Practice was developed to assist practitioners with implementing the research findings. The manual contains several components. An implementation flowchart is provided that indicates steps to take to enhance and maintain innovation. The flowchart presents overarching guidelines to follow to generate innovative ideas, create opportunities for innovative change to occur, and foster diffusion of innovations throughout a firm and the construction industry. Suggested practices are given for each guideline to offer examples for practical implementation. Guidelines and suggested practices are provided that apply at both the project and firm levels and, when applied, are intended to enhance innovation on construction projects. The manual can be obtained on the Pankow Reports webpage under Publications on the SPUR (San Francisco Planning & Urban Research Association) website at: www.spur.org/pankowreports/.

7.3 Innovation Slide Presentation

A slide presentation was created to present the research in an electronic format on-line. The presentation provides those interested in the research a means to quickly learn about the study and results, and provides a resource for communicating the study results to others for education and training purposes. The slide presentation can be viewed and downloaded from the Pankow Reports webpage under Publications on the SPUR (San Francisco Planning & Urban Research Association) website at: www.spur.org/pankowreports/.

7.4 Monograph

A monograph is available that provides this research report in a condensed format. The monograph extracts the salient results of the final report and manual of practice, condensed to approximately 20-30 pages. It is designed to be read and used by integrated project delivery practitioners in developing the means and methods to encourage innovation in their projects. Similar to the other documents described above, the monograph is available from the Pankow Reports webpage under Publications on the SPUR (San Francisco Planning & Urban Research Association) website at: www.spur.org/pankowreports/.

7.5 Papers and Presentations

Slide presentations of the preliminary and final research findings were created and presented at the 2006 and 2007 Design-Build Institute of America (DBIA) Annual Conferences in Nashville, TN, in October 2006, and in Dallas, TX, in October-November, 2007. In addition, the following paper describing the research study and findings was presented at the 2007 Construction Research Congress sponsored by the ASCE Construction Institute, and is published in the conference proceedings:

> Gambatese, J.A., Hallowell, M., and Sillars, D.N. (2007). "Benchmark of Innovation in the Architecture/Engineering/Construction Industry." *Proceedings of the 2007 Construction Research Congress*, ASCE, Grand Bahama Island, Bahamas, May 6-8, 2007.

It is anticipated that a second paper containing the final research results will be written for publication in an academic journal.

8.0 REFERENCES

Abd El Halim, O. and Haas, Ralph (2004). “Process and case illustration of construction innovation.” *Journal of Construction Engineering and Management*, ASCE, 130(4), 570-573.

Ahmad, I. (1991). “Restructuring responsibility and reward for more construction innovation.” *Preparing for Construction in the 21st Century: Proceedings of the Construction Congress 1991*, L.M. Chang, Ed., ASCE, 453-458.

Arditi, D., Kale, S., and Tangkar, M. (1997). “Innovation in construction equipment and its flow into the construction industry.” *Journal of Construction Engineering Management*, ASCE, 123(4), 371-378.

Bernstein, H.M., Kissinger, J.P., and Kirksey, W. (1998). “Moving innovation into practice.” *Civil Engineering in the Asia Region: Proceedings of the First International Civil Engineering Conference*, E.A. Downey, Ed., ASCE, 250-259.

Bossink, B.A.G. (2004). “Managing drivers of innovation in construction networks.” *Journal of Construction Engineering and Management*, ASCE, 130(3), 337-345.

Cameron K.S. and Quinn, R.E. (1999). *Diagnosing and Changing Organizational Culture*. Addison-Wesley Publishing Company, Inc., Reading, MA.

Christensen, C.M. (1997). *The Innovator’s dilemma: When new technologies cause great firms to fail*. Harvard Bus. School Press, Boston, Mass., 225 pp.

Christensen, C.M. and Raynor, M.E. (2003). *The Innovator’s Solution: Creating and Sustaining Successful Growth*. Harvard Business School Press, ISBN 1-57851-852-0.

CII/NSF (1997). “How Do We Use Research to Improve the Engineering and Construction Industry?” Final Report, NSF Contract #9700436 CMS, Workshop Co-sponsored by CII and NSF, Austin, TX, May 13-14, 1997.

Dikmen, I.M., Birgonul, T., and Artuk, S.U. (2005). “Integrated framework to investigate value innovations.” *Journal of Management in Engineering*, ASCE, 21(2), 81-90.

Dulaimi, M. (1995). “The challenge of innovation in construction.” *Building Research and Information*, Taylor & Francis, 23(2), 106-109.

Egbu, C.O. (2001). “Managing innovation in construction organisations: An examination of critical success factors.” *Perspectives on Innovation in Architecture, Engineering and Construction*. Anumba, C.J., Egbu, C., and Thorpe, A., Eds., Centre for Innovative Construction Engineering, Loughborough University, Loughborough, Leicestershire, U.K.

ENR (2006). “Who Will Pay for Project Delivery Process Innovation?” *Engineering News-Record*, McGraw-Hill, Inc., New York, NY, Nov. 27, 2006.

Henry, D. (2006). "Creativity Pays. Here's How Much." *BusinessWeek Online*, <http://biz.yahoo.com/special/innovation06_article2.html>, April 28, 2006.

Hofstede, G. and Hofstede, G.J. (2005). *Cultures and Organizations: Software of the Mind*. McGraw-Hill, Inc., New York, NY.

Jones, M. and Saad, M. (2003). *Managing Innovation in Construction*. Thomas Telford Publishing, London.

Kangari, R., and Miyatake, Y. (1997). "Developing and managing innovative construction technologies in Japan." *Journal of Construction Engineering and Management*, ASCE, 123(1), 72-80.

Kelley, T. (2005). *The Ten Faces of Innovation*. Doubleday, New York, NY.

Koebel, C.T., Papadakis, M., Hudson, E., and Cavell, M. (2004). "The Diffusion of Innovation in the Residential Building Industry." Center for Housing Research, Virginia Polytechnic Institute, Blacksburg, VA and NAHB Research Center, Upper Marlboro, MB.

Macomber, J.D. (2002). "Follow the money: What really drives construction innovation." *Proceedings from the Construction Research Congress*, ASCE, 1-9.

Madewell, C.J. (1986). "Innovative solutions to the challenges of heavy civil projects." *Constr. Innovation: Demands, Successes and Lessons, Proc., Constr. Div. of ASCE in conjunction with ASCE Convention,* Seattle, Washington, Tatum, C.B., Ed., ASCE, 11-17.

Park, M., Nepal, M., and Dulaimi, M. (2004). "Dynamic modeling for construction innovation." *Journal of Management in Engineering,* ASCE, 20(4), 170-177.

Rogers, E.M. (1995). *Diffusion of Innovations (4th Ed).* New York, NY: Free Press.

Ryan, B. and Gross, N.C. (1943). "The Diffusion of Hybrid Seed Corn in Two Iowa Communities." *Rural Sociology*, 8(1): 15–24.

Schein, E. (1999). *The Corporate Culture Survival Guide*. Jossey-Bass, New York, NY.

Slaughter, E.S. (1993). "Builders as sources of construction innovation." *Journal of Construction Engineering and Management*, ASCE, 119(3), 532-549.

Slaughter, E.S. (1998). "Models of construction innovation." *Journal of Construction Engineering and Management*, ASCE, 124(3), 226-231.

Steel, J. (2001). "Planning and managing innovation and diffusion in construction." *Perspectives on Innovation in Architecture, Engineering and Construction*. Anumba, C.J., Egbu, C., and

Thorpe, A., Eds., Centre for Innovative Construction Engineering, Loughborough University, Loughborough, Leicestershire, U.K.

Tatum, C.B. (1986a). “Demands and means for construction innovation.” *Constr. Innovation: Demands, Successes and Lessons: Proc., Constr. Div. of ASCE in conjunction with ASCE Convention*, Seattle, Washington, Tatum, C.B., Ed., ASCE, 31-43.

Tatum, C.B. (1986b). “Potential mechanisms for construction innovation.” *Journal of Construction Engineering and Management*, ASCE, 112(2), 178-191.

Tatum, C.B. (1991). “Incentives for technological innovation in construction.” *Preparing for Constr. in the 21st Century: Proc. of Constr. Congress 1991*, Chang, L.M., Ed., ASCE, 447-452.

Toole, T.M. (2001). “Technological trajectories of construction innovation.” *Journal of Architectural Engineering*, ASCE, 7(4), 107-114.

Train, A. and Egbu, C. (2006). “Maximising the Impact of Knowledge for Innovation in Gaining Competitive Advantage.” *Proceedings of the Annual Research Conference of the Royal Institution of Chartered Surveyors*, COBRA 2006, University College, London, Sept. 7-8, 2006.

Tucker, R. (2004). “Innovation network.” *Innovation Metrics: Embedding Innovation in an Organization's Systems*. ThinkSmart, <www.thinksmart.com>, May 29, 2006.

Turrell, M. (2006). “Show me the numbers: A look at innovation metrics.” *Innovation Tools*. <www.innovationtools.com/Articles/EnterpriseDetails>, May 29, 2006.

Waterman, R. Jr., Peters, T., and Phillips, J.R. (1980). “Structure is not Organization.” *Business Horizons*, Edward Elgar Publishing, 23(3), June 1980, 14-26.

9.0 APPENDIX

9.1 Benchmarking Survey Cover Letter and Questionnaire

The following documents are the cover letter and questionnaire that were distributed electronically as part of the innovation benchmarking survey. Additional, open-ended questions that were only asked in the interviews are included at the end of the questionnaire.

Department of Civil, Construction and Environmental Engineering
Oregon State University
202 Apperson Hall, Corvallis, Oregon 97331-2302 USA
Tel: 541-737-4934 | Fax: 541-737-3300 | http://ccee.oregonstate.edu/

July 24, 2006

Dear Sir or Madam:

OSU Construction Engineering Management is conducting a research study titled "Energizing Innovation in Integrated Project Delivery" and desires your input on the innovation that occurs on your projects and within your firm. We ask for your help with this study by completing a short survey regarding innovation. The survey is located at the following link: http://web.engr.oregonstate.edu/~hallowem/InnovationWebSurvey.html. In addition to some general background information questions, the survey contains 28 questions and is designed to be completed in approximately 10 minutes. In appreciation for completing the survey we are happy to send you a summary of the survey results.

The goal of the study is to enhance the ability of the construction industry to innovate in its delivery of construction projects through integrated project delivery processes. The research involves determining the factors that impact innovation on a project and the practices and processes that encourage and facilitate innovation. An outcome of the study will be an implementation plan which the construction industry can use to employ practices that enhance innovation on projects. The study is funded by a partnership between the Foundation for Integrated Services and the Charles Pankow Foundation.

Please respond to only those questions that you feel qualified to answer. Your responses, together with those from other respondents, will be combined and used for statistical summaries only. All individual responses will be kept confidential and not be used for anything unrelated to this study. Summarized data will not identify individual participants or companies.

If you have any questions about this study, please contact Dr. John Gambatese (Principal Investigator) at john.gambatese@oregonstate.edu, or Matthew Hallowell at hallowem@onid.orst.edu.

Thank you very much for taking the time to participate in this important study.

Sincerely,

John Gambatese
Assistant Professor, Construction Engineering Management

Matthew Hallowell
PhD Student

SURVEY OF INNOVATION IN THE ARCHITECTURE/ENGINEERING/CONSTRUCTION (A/E/C) INDUSTRY

Thank you for taking the time to complete this survey. Please answer the following questions, providing as much detail as possible where requested. When you have finished answering the questions, submit your response using the “"Submit"” button at the end of the survey.

Please respond to only those questions that you feel qualified to answer. **Your individual responses will be kept confidential and not be used for anything unrelated to this study. Summarized data will not identify individual participants or companies.**

Any information that you can share is greatly appreciated! Your response will become a vital component of our research project and ultimately benefit the A/E/C industry. In appreciation for completing the survey, we are happy to send you a summary of the survey results.

If you have any questions about this survey or about the research project in general, please do not hesitate to contact us at: hallowem@onid.orst.edu or john.gambatese@oregonstate.edu.

BACKGROUND INFORMATION

Your job title: ☐

Years of experience in the architecture/engineering/construction (A/E/C) industry: ☐ yrs.

Years of experience in your specialty field: ☐ yrs.

Your geographic location: City: ☐ State: ☐

Firm headquarters location, if different than above: City: ☐ State: ☐

Firm’s approximate annual revenue: $ ☐

Type(s) of facilities your firm typically works on (Select all that apply):

☐ Industrial	☐ Residential Buildings (single family)	☐ Utilities – Power
☐ Manufacturing	☐ Residential Buildings (multi-family)	☐ Utilities - Water Supply

☐ Transportation	☐ Commercial/Office Buildings	☐ Utilities – Sewer/waste
☐ Petroleum	☐ Hazardous waste	☐ Other: ____

Approximate percentage distribution of the service(s) which your firm provides:

____ % Architectural design	____ % Site Development
____ % Engineering design	____ % Program Management
____ % Construction management	____ % Specialty contracting - CSI division(s): ____
____ % General contracting	____ % Other: ____

Approximate percentage distribution between public and private work by your firm:

____ % Public

____ % Private

Approximate percentage distribution of the type of work by your firm:

____ % New construction

____ % Renovation/remodel

____ % Maintenance/repair

Approximate percentage distribution of project delivery methods in which your firm participates:

____ % Design-Bid-Build	____ % CM-at-risk
____ % Design-Build	____ % Construction manager/General Contractor (CM/GC)
____ % CM (agency relationship only)	____ % Other: ____

If your firm participates in Design-Build projects, how is the Design-Build team structured? (Select all that apply.)

☐ Your firm performs both the design and build scopes of work with internal capabilities

☐ Your firm subcontracts a portion of the work to another firm

☐ Your firm is a subcontractor to another firm

☐ Joint venture/partnership with your firm as the lead

☐ Joint venture/partnership with another firm as the lead

☐ Other: ____

INNOVATION ON YOUR PROJECTS AND IN YOUR FIRM

For the following questions, please rate and describe your firm based on your personal experience. Please use the following definition for innovation:

> **Innovation is 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. Innovation includes both the generation of a new product, technology, or process, and its implementation. Additionally, innovation may be the application of a product, technology, or process that already exists but is just new to the organization adopting it.**

1. What new products, technologies, or processes, that either your firm developed or were developed outside your firm, have been implemented on your projects or within your firm in the past 10 years?

2. Where do the ideas for the innovations typically originate?

☐ % that originate from within the firm (internally)

☐ % that originate from outside the firm (externally)

3. If the ideas for the innovations originate **internally**, at what level do they typically originate? (Select all that apply)

☐ Field worker	☐ Project Architect
☐ Foreman	☐ Project Manager
☐ Superintendent	☐ Upper Management
☐ Project Engineer	☐ Other (Please describe):

4. If the ideas for the innovations originate **externally**, from where do they typically come from? (Select all that apply)

☐ Architect	☐ Supplier	☐ Subcontractor
☐ Design engineer	☐ Construction Manager	☐ Other industry (Please indicate which industries):

☐ Owner/client	☐ Program Manager	☐ Other: ____
☐ General contractor	☐ Developer	

5. What is typically the impetus for the innovations? (Select all that apply)

☐ Cost savings	☐ Improve safety
☐ Schedule reduction	☐ Competitive advantage
☐ Increase productivity/efficiency	☐ Entrance into a new market
☐ Improve quality	☐ Other ____

6. How often are new products, technologies, or processes introduced on your projects or in your firm?

   ____ innovations per year

7. What is the approximate average number of man-hours expended developing and implementing each innovation?

   ____ worker-hours per innovation

8. What is the approximate average time from initial concept through implementation of an innovation?

   ____ months per innovation

9. Does your firm set aside a portion of its annual budget for the development and implementation of new products, technologies, or processes? If so, what percentage is budgeted for innovation activities?

   ○ Yes, Percent of annual budget = ____%

   ○ No

10. Are there employees within your firm who are responsible for seeking out, developing, and implementing new products, technologies, or processes? If so, how many employees, and what percentage of their work is devoted to this responsibility?

    ○ Yes, Number of employees = ____ Average percent of work = ____%

    ○ No

11. Does your firm have a formal plan for developing and implementing new products, technologies, or processes (i.e., an Innovation Plan)?

- Yes
- No

If yes, please describe:

12. To what extent is innovation linked to the overall organizational strategy of your firm?

- Not at all
- A minor part of the organizational strategy
- Moderately incorporated into the organizational strategy
- An integral part of the organizational strategy
- It is the basis for the organizational strategy
- Don’t know

13. To what extent are your firm's innovation experience and successes used to market your firm?

- Not at all
- A minor part of the marketing strategy
- Moderately incorporated into the marketing strategy
- An integral part of the marketing strategy
- It is the basis for the marketing strategy
- Don’t know

14. What barriers exist, either within your firm or external to your firm, which limit innovation within your firm? (Select all that apply)

Risk of failure	Not recognized by clients
Competitive bidding	Rate of failure of new products/ technologies
Low investment in research and development (R&D)	Not applicable to all projects
Long payback period	Loss of profit
Low return on investment	Project delivery method

☐ Lack of communication	☐ No direct benefit from innovation (i.e., others benefit)
☐ Lack of personal incentives	☐ Fear of change
☐ Lack of corporate incentives	☐ No barriers
☐ Industry regulations and codes	☐ Other:

15. What facilitates/enables innovations within your firm (Select all that apply)?

☐ A culture of innovation within your firm	☐ Overlap of design and construction phases
☐ Level of communication within your firm	☐ Complexity/sophistication of projects
☐ Level of communication amongst project team members	☐ Sophistication/expertise of competitors
☐ Support from upper management in the firm	☐ A “champion” of the innovation within the project/firm
☐ Support from the owner/client	☐ No enablers
☐ Available funds	☐ Other:
☐ Project delivery method	

16. Using a scale of 1 to 5, please rate your firm’s ability to innovate within the following project delivery methods (1 = high ability to innovate; 3 = moderate ability to innovate; 5 = low ability to innovate):

a. Design-Bid-Build
b. Design-Build
c. CM (agency relationship only)
d. CM-at-Risk
e. Construction manager/General Contractor (CM/GC)

17. What are the impacts/outcomes of innovation within your firm? (Select all that apply)

☐ Increased productivity	☐ Improved safety
☐ Increased market share	☐ Competitive advantage

☐ Appearance of new markets	☐ Marketing
☐ Cost savings	☐ No impacts
☐ Improved quality	☐ Other:

18. How much do the innovations in your firm contribute to the overall percentage of profit earned by your firm?

- None
- A small percentage
- A moderate percentage
- A large percentage
- A very high percentage
- Don’t know

19. For those employees who develop new products, technologies, or processes for your firm, to what extent are the employees supported, recognized, and rewarded for their work on the innovations?

- Never
- Sometimes
- Frequently
- Most of the time
- All of the time
- Don’t know

20. To what extent does your firm emphasize (value) innovation on projects or within the firm?

- Not at all
- An insignificant amount
- A moderate amount
- Valued to a great extent
- Top priority
- Don’t know

21. How would you rate the **level of innovation** that occurs on your projects and in your firm?

- None
- Low

- Moderate
- High
- Very high
- Don't know

22. How would you rate your firm's **ability to innovate** compared to other similar organizations in the A/E/C industry?

- Much less
- A little less
- About the same
- A little more
- Much more
- Don't know

23. How would you rate your firm's ability to **envision** new products, technologies, or processes?

- Very low
- Below average
- Average
- Above average
- Very high
- Don't know

24. How would you rate your firm's ability to **implement** new products, technologies, or processes?

- Very low
- Below average
- Average
- Above average
- Very high
- Don't know

25. To what extent are there formal mechanisms in your firm to capture and share lessons learned associated with the innovations that occur in your firm?

- Not at all

- A small amount
- A moderate amount
- A significant amount
- Very extensive
- Don’t know

26. How does your firm measure the success/failure of an innovation? (Select all that apply)

Not at all	Schedule performance
Budget analyses	Quality performance
Productivity analyses	Safety performance
Client feedback	Increase in market share
Project team input/comments	Other:

27. Please rate you firm’s ability to measure and track innovations:

- None
- Low
- Moderate
- High
- Very high
- Don’t know

28. How important to your firm is measuring and tracking the success/failure of an innovation?

- Not at all
- Minimally important
- Moderately important
- Significantly important
- Extremely important
- Don’t know

ADDITIONAL INFORMATION

May we contact you for further information on this topic in the future?

- Yes

No

If yes, and to receive a summary of the survey results, please provide your contact information below:

Full Name:

Email Address:

Phone Number:

Please provide any additional comments about innovation in the A/E/C industry below.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE! YOUR INPUT IS VERY VALUABLE TO THE RESEARCH PROJECT!

Submit

ADDITIONAL QUESTIONS FOR INTERVIEWS:

With your innovations in mind…

30. What was the driving force behind these innovations?

31. Would the innovation have been achieved without these driving forces?

32. What about your organization facilitates innovation?

33. What about your organization impedes innovation?

34. What are the most influential external forces that affect innovation (enablers and barriers)?

35. How do you overcome the internal and external barriers?

9.2 Innovative Products Survey Cover Letter and Questionnaire

The following documents are the cover letter and questionnaire that were distributed electronically as part of the innovation benchmarking survey.

Dear ____________________:

OSU Construction Engineering Management is conducting a research study titled "Energizing Innovation in Integrated Project Delivery" and desires your input regarding "_(name of innovation)___________ ." We obtained your contact information from Construction Industry Institute's (CII) "Emerging Construction Technologies" website. We ask for your help with our study by completing a short survey regarding innovation. If you are not the appropriate person to contact please forward this email to the appropriate person. The survey is located at the following link: http://web.engr.oregonstate.edu/~hallowem/IPS.htm

In addition to some general background information questions, the survey contains 29 questions and is designed to be completed in approximately 20 minutes. In appreciation for completing the survey we are happy to send you a summary of the survey results.

The goal of the study is to enhance the ability of the construction industry to innovate in its delivery of construction projects through integrated project delivery processes. The research involves determining the factors that impact innovation on a project and the practices and processes that encourage and facilitate innovation. An outcome of the study will be an implementation plan which the construction industry can use to employ practices that enhance innovation on projects. The study is funded by a partnership between the Foundation for Integrated Services and the Charles Pankow Foundation.

Please respond to only those questions that you feel qualified to answer. Your responses, together with those from other respondents, will be combined and used for statistical summaries only. All individual responses will be kept confidential and not be used for anything unrelated to this study. Summarized data will not identify individual participants or companies.

If you have any questions about this study, please contact Dr. John Gambatese (Principal Investigator) at john.gambatese@oregonstate.edu, or Matthew Hallowell at hallowem@onid.orst.edu.

Thank you very much for taking the time to participate in this important study.

Sincerely,

Matthew Hallowell
PhD Candidate

John Gambatese
Associate Professor, Construction Engineering Management

Thank you for taking the time to complete this survey. Please answer the following questions, providing as much detail as possible where requested. When you have finished answering the questions, submit your response using the "Submit" button at the end of the survey.

Please respond to only those questions that you feel qualified to answer. **Your individual responses will be kept confidential and not be used for anything unrelated to this study. Summarized data will not identify individual participants or companies.**

Please avoid pressing "Enter" before you are finished as it will prematurely end the survey.

Any information that you can share is greatly appreciated! Your response will become a vital component of our research project and ultimately benefit the A/E/C industry. In appreciation for completing the survey, we are happy to send you a summary of the survey results.

If you have any questions about this survey or about the research project in general, please do not hesitate to contact us at: hallowem@onid.orst.edu or john.gambatese@oregonstate.edu

Personal Information

1.) Your job title: ______

2.) Years of experience in the architecture/engineering/construction (A/E/C) industry: ______ yrs.

3.) Title of your firm's innovation: ______

4.) Please describe the extent of your involvement in the following phases associated with your innovation:

	Not at all	**Very little**	**Some**	**Significant**	**Integral**
Conception	☐	☐	☐	☐	☐
Research and development	☐	☐	☐	☐	☐
Implementation	☐	☐	☐	☐	☐

The Organization

5.) Types of service(s) which your firm provides (Select all that apply):

☐ Architectural design	☐ Site Development
☐ Engineering design	☐ Program Management
☐ Construction management	☐ Specialty contracting - CSI division(s):
☐ General contracting	☐ Other:

6.) Please describe the extent of your innovation's impact on your firm's:

	None	Very little	Some	Significant	Extreme
Overall success	○	○	○	○	○
Market share	○	○	○	○	○
Profitability	○	○	○	○	○

7.) Would your firm exist without the innovation (i.e. Is the innovation the sole or primary source of income for your firm)?

- ○ Yes
- ○ No

8.) Are there competing products/processes/technologies from other firms? If yes, please name the competing product/process/technology.

- ○ Yes
- ○ No

Conception of the Innovation

9.) What employees of your firm can be credited with the introduction of this innovation? Please provide individuals job titles in lieu of names.

10.) Where did the idea for the innovation originate? (Please check all that apply.)

☐ Adapted from another industry
☐ Independently generated by your firm
☐ Generated by another firm in the A/E/C industry
☐ Other, please describe

Research and Development (R&D)

11.) Was there R&D for this particular innovation? If no, please proceed to question #15

- Yes
- No

12.) What members of your firm participated in R&D activities? (Select all that apply)

☐ Field worker	☐ Project Architect
☐ Foreman	☐ Project Manager
☐ Superintendent	☐ Upper Management
☐ Project Engineer	☐ Other (Please describe):

13.) Please describe the nature and extent of R&D activities:

14.) What was the resource investment in R&D activities?

Total Duration		months
Worker Hours		hours
Approximate Budget		US Dollars

Implementation

15.) When was your innovation first developed and ready for widespread use?

Month Year

16.) What is the approximate cost to a firm to implement your innovation?

US Dollars

17.) What type of firm **implements** the innovation? (Select all that apply)

☐ Architectural design	☐ Site Development
☐ Engineering design	☐ Program Management
☐ Construction management	☐ Specialty contracting - CSI division(s):
☐ General contracting	☐ Other:

18.) Please describe the extent of the following:

	None	**Very little**	**Some**	**Significant**	**Extreme**
Skill level required to implement the innovation	○	○	○	○	○
Marketing of your innovation	○	○	○	○	○
Diffusion of your innovation into the A/E/C industry	○	○	○	○	○
Training required to implement the innovation	○	○	○	○	○

19.) Is there a companion product, process or technology required to implement your innovation?

- Yes
- No

20.) If yes, what is the cost of this companion product, process or technology?

[ ] US Dollars

Motivation

21.) Please rate the following as motivators for implementing your innovation? (i.e., Why would a firm choose to implement this innovation?)

Motivator	None	Small	Moderate	Significant	Extreme
Increased productivity					
Increased market share					
Appearance of new markets					
Cost savings					
Improved quality					
Improved safety					
Competitive advantage					
Marketing					
Other:					
Other:					

Barriers

22.) Please rate the following as barriers to implementation of the innovation:

Barrier	None	Small	Moderate	Significant	Extreme
Risk of failure					
Competitive bidding					
Low investment in R&D					
Long payback period					

Low return on investment	☐	☐	☐	☐	☐
Lack of communication	☐	☐	☐	☐	☐
Lack of personal incentives	☐	☐	☐	☐	☐
Lack of corporate incentives	☐	☐	☐	☐	☐
Industry regulations and codes	☐	☐	☐	☐	☐
Not recognized by clients	☐	☐	☐	☐	☐
Rate of failure	☐	☐	☐	☐	☐
Not applicable to all projects	☐	☐	☐	☐	☐
Loss of profit	☐	☐	☐	☐	☐
Project delivery method	☐	☐	☐	☐	☐
No direct benefit from innovation	☐	☐	☐	☐	☐
Fear of change	☐	☐	☐	☐	☐
Technical capabilities	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐

Enablers

23.) Please rate the following as enablers to implementation of the innovation:

Enabler	**None**	**Small**	**Moderate**	**Significant**	**Extreme**
A culture of innovation within the firm	☐	☐	☐	☐	☐
Level of communication within the firm	☐	☐	☐	☐	☐
Level of communication amongst project team members	☐	☐	☐	☐	☐
Support from upper management in the firm	☐	☐	☐	☐	☐

Support from the owner/client	☐	☐	☐	☐	☐
Available funds	☐	☐	☐	☐	☐
Project delivery method	☐	☐	☐	☐	☐
Overlap of design and construction phases	☐	☐	☐	☐	☐
Complexity/sophistication of projects	☐	☐	☐	☐	☐
Sophistication/expertise of competitors	☐	☐	☐	☐	☐
A "champion" of the innovation within the project/firm	☐	☐	☐	☐	☐
Availability of technical resources	☐	☐	☐	☐	☐
Other: ____	☐	☐	☐	☐	☐

24.) Was there a "champion" for this innovation (i.e. an individual who aggressively supported and promoted the innovation)? If yes, please describe the individual's role in promoting development and/or implementation of the innovation.

☐ Yes ____

☐ No

Outcomes

25.) Please rate the following outcomes that you have observed from implementation of this innovation.

Outcome	**None**	**Small**	**Moderate**	**Significant**	**Extreme**
Increased productivity	☐	☐	☐	☐	☐
Increased market share	☐	☐	☐	☐	☐
Appearance of new markets	☐	☐	☐	☐	☐
Cost savings	☐	☐	☐	☐	☐
Improved quality	☐	☐	☐	☐	☐
Improved safety	☐	☐	☐	☐	☐

Competitive advantage					
Marketing					
Other:					
Other:					

Metrics

26.) How would a firm measure and track the effectiveness of this innovation?

27.) Please rate the ability of the following metrics to measure and track the effectiveness of the innovation:

Metric	None	Small	Moderate	Significant	Extreme
Cost performance					
Productivity					
Client feedback					
Project team input/comments					
Schedule performance					
Quality performance					
Safety performance					
Market share					
Other:					
Other:					

Organization's Innovation Structure

28.) Please indicate if your firm has the following elements:

Structure Elements	Yes	No

Innovation budget	☐	☐
Employees dedicated to innovation	☐	☐
Formal innovation plan	☐	☐
Formal innovation meetings	☐	☐
Formal methods for capturing and disseminating lessons learned	☐	☐

Organization's Innovation Climate

29.) Please rate the extent to which your firm encourages or performs the following:

Climatological Elements	**None**	**Small**	**Moderate**	**Significant**	**Extreme**
Management support of innovation	☐	☐	☐	☐	☐
Employee recognition for innovation	☐	☐	☐	☐	☐
Encouragement to try something new	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Communication	☐	☐	☐	☐	☐
Formal innovation meetings	☐	☐	☐	☐	☐

Additional Information

May we contact you for further information on this topic in the future?

☐ Yes

☐ No

If yes, and to receive a summary of the survey results, please provide your contact information below:

Full Name: ______

Email Address:

Phone Number:

Please provide any additional comments about innovation in the A/E/C industry below.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE!
YOUR INPUT IS VERY VALUABLE TO THE RESEARCH PROJECT!

Submit

9.3 List of Innovative Products

The following is the list of the 233 products that were collected from the Internet search. Innovation surveys were distributed to the manufacturers of 189 of these products (those with working e-mail addresses).

	Innovation Name	Year	Source
1	Project Information Management System	2006	Nomination (NOVA)
2	Asphalt Pavement Tapered Edge Form	2006	Nomination (NOVA)
3	5D Virtual Construction	2006	Nomination (NOVA)
4	Relocatable Safety Enclosures	2006	Nomination (NOVA)
5	Large Retaining Wall Concrete Blocks	2006	Nomination (NOVA)
6	Prefab Gfrp Concrete Bridge Deck Panels	2006	Nomination (NOVA)
7	Asphalt Pavement Radar Analysis	2006	Nomination (NOVA)
8	Patterned Extruded Concrete Walls	2006	Nomination (NOVA)
9	Self-Compacting/Sealing Aggregate	2006	Nomination (NOVA)
10	Pneumatic Capsule Pipeline	2006	Nomination (NOVA)
11	Water Main Renewal Planner	2006	Nomination (NOVA)
12	Concrete Ready-Mix Truck Wash Out Bin	2006	Nomination (NOVA)
13	Wireless Electric Switch Controls	2006	Nomination (NOVA)
14	Gross Solids Removal Devices	2006	Nomination (NOVA)
15	Military to Construction Transition	2006	Nomination (NOVA)
16	White Pozzolans From Waste Glass	2006	Nomination (NOVA)
17	Lean Production Management	2006	Nomination (NOVA)
18	Highway Asphalt Paver Fume Controls	2006	Nomination (NOVA)
19	3d-Enabled/Lean Design/Construction	2006	Nomination (NOVA)
20	Field Welding Polyethylene Pipe	2006	Nomination (NOVA)
21	Project Worker Stabilization Agreement	2006	Nomination (NOVA)
22	Site Subsurface Characterization/Analysis	2006	Nomination (NOVA)
23	Transportation Programmatic Permitting	2006	Nomination (NOVA)
24	Wind Design Guide and Standard	2006	Nomination (NOVA)
25	Web-Based Project Management	2006	Nomination (NOVA)
26	Ripping Backhoe Buckets	2006	Nomination (NOVA)
27	Electronic Project Control System	2006	Nomination (NOVA)
28	Buckling Restrained Braced Frames	2006	Nomination (NOVA)
29	Post-Tensioned Steel Frames	2006	Nomination (NOVA)
30	Soy Based Polyurethane Foam	2005	Nomination (NOVA)
31	Owner’s Contractor Safety Orientation	2005	Nomination (NOVA)
32	Pipeline Leak Noise Correlator	2005	Award Winner (NOVA)
33	Cold Weather Concrete Additive	2005	Nomination (NOVA)
34	Asphalt Milling Attachments	2005	Award Winner (NOVA)
35	Laser-Based Aggregate Scanning	2005	Award Winner (NOVA)
36	Window Selection Tool	2005	Nomination (NOVA)
37	FRP Concrete Hybrid Bridge Deck	2005	Nomination (NOVA)
38	Handtruck for Transporting Toilets	2005	Nomination (NOVA)

39	Online Contractor Badging	2005	Nomination (NOVA)
40	Construction Wastewater Filtration	2005	Award Winner (NOVA)
41	Eco-Block in the Villages of Rio Del Sol	2005	Nomination (NOVA)
42	Core-Clear Horizontal Cmu Reinforcing	2005	Nomination (NOVA)
43	Modeling Fire Resistance of Walls	2005	Nomination (NOVA)
44	Concrete Bridge Deck Management	2005	Nomination (NOVA)
45	Table Top Box Building Structure	2005	Nomination (NOVA)
46	Robotic Highway Safety Markers	2005	Nomination (NOVA)
47	Hybrid Concrete / FRP Bridges	2005	Nomination (NOVA)
48	Performance-Based Car Park Ventilation	2005	Nomination (NOVA)
49	Wire Clip-On Reinforcing Tie	2005	Nomination (NOVA)
50	Lightweight, High Strength Concrete Panels	2005	Nomination (NOVA)
51	Laboratory Design Toolkit	2005	Nomination (NOVA)
52	Lifting Fully Assembled Bridges	2005	Nomination (NOVA)
53	Electro-Osmotic De-Moisturizing	2005	Nomination (NOVA)
54	Tieback Installation Machine	2005	Nomination (NOVA)
55	Prefabricated Reinforcing Cage	2005	Nomination (NOVA)
56	Highway Median Truck Access Ramp	2004	Nomination (NOVA)
57	Woman Worker Training, Support	2004	Nomination (NOVA)
58	Blast Threat Analysis	2004	Nomination (NOVA)
59	Structural Genome System	2004	Nomination (NOVA)
60	Object Genome System	2004	Nomination (NOVA)
61	Formaldehyde-Free Fiber Glass	2004	Nomination (NOVA)
62	Tunnel Jacking For Boston Central Artery	2004	Nomination (NOVA)
63	Integrated Precast Concrete Deck Panels	2004	Nomination (NOVA)
64	Integrated Precast Concrete Deck Panels	2004	Nomination (NOVA)
65	Rouge Complex Sustainability Project	2004	Nomination (NOVA)
66	Elevated Hand Tool Support	2004	Nomination (NOVA)
67	Helix Shaped Steel Fiber Reinforcing	2004	Nomination (NOVA)
68	ISO 9001:2000 in State DOT	2004	Nomination (NOVA)
69	Bridge Precast Substructure Units	2004	Nomination (NOVA)
70	Bridge Precast Substructure Units	2004	Nomination (NOVA)
71	Nursing Home With Comforts Of Home	2004	Nomination (NOVA)
72	Mortarless Masonry Wall System	2004	Nomination (NOVA)
73	Project Rework Reduction Tool – PRRT	2004	Nomination (NOVA)
74	Micro-Composite Resteel	2004	Nomination (NOVA)
75	Prestressed Strand Bridge Superstructure	2004	Nomination (NOVA)
76	New Precast Bridge Deck Panels	2004	Nomination (NOVA)
77	Plastic Subsurface Stormwater System	2004	Nomination (NOVA)
78	Personal Mobile Crane Simulator	2004	Nomination (NOVA)
79	Giant Bronze Cast Budha	2004	Nomination (NOVA)
80	Fiber-Reinforced Polymer Rebar	2003	Nomination (NOVA)
81	Pallet Barrier Flood Fighting	2001	Nomination (NOVA)
82	National Certification of Crane Operators	2001	Nomination (NOVA)
83	Modular Units	2001	Nomination (NOVA)
84	Fused Plastic Pipe Joint Jacket	2002	Nomination (NOVA)
85	Digital Close-Range Photogrammetry	2003	Nomination (NOVA)

86	Automatic Rebar Tying Machine	2003	Nomination (NOVA)
87	Insulating Concrete Forms	2003	Nomination (NOVA)
88	Laser Decontamination of Metal	2003	Nomination (NOVA)
89	Control Network Technology on a Chip	2003	Nomination (NOVA)
90	Contractor Web-Based Training	2003	Nomination (NOVA)
91	Holistic “Green” Office Building	2003	Nomination (NOVA)
92	Ultra-High Performance Ductile Concrete	2003	Nomination (NOVA)
93	Launched Steel Girder Bridge Erection	2003	Nomination (NOVA)
94	Remote Data Entry Daily Timesheet	2003	Nomination (NOVA)
95	Plastic Covered Steel Guardrails	2003	Nomination (NOVA)
96	Internet Tracking of Worker Status	2003	Nomination (NOVA)
97	Work Flow Management	2003	Nomination (NOVA)
98	Team-Based Building Design Program	2003	Nomination (NOVA)
99	Internet Based Plan Room	2003	Nomination (NOVA)
100	Embedded Galvanic Anode	2003	Nomination (NOVA)
101	Behavior Based Safety	2003	Nomination (NOVA)
102	Joint Operator & Ironworker Training	2003	Nomination (NOVA)
103	Dense Polyethylene Slab Blockout	2003	Nomination (NOVA)
104	Internet Plan Room Information Network	2003	Nomination (NOVA)
105	Gas Main Inspection	2003	Nomination (NOVA)
106	Aerial Concrete Wall Sawing And Drilling	2003	Nomination (NOVA)
107	On-Line Bidding Exchange	2003	Nomination (NOVA)
108	Fiber Reinforced Polymer (FRP) Reinforcing	2003	Nomination (NOVA)
109	Rapid Response Mobile Training	2001	Nomination (NOVA)
110	Careers Web Site	2001	Nomination (NOVA)
111	On-Site Drug-Screening	2001	Nomination (NOVA)
112	Electric Contact Breaker	2001	Nomination (NOVA)
113	Fiber Optic Cable in Sewers	2001	Nomination (NOVA)
114	CRIB POST Hydraulic System	2001	Nomination (NOVA)
115	Concrete Pulverizer With Ripper	2002	Nomination (NOVA)
116	Slotted Web Steel Beam-to-Column	2002	Nomination (NOVA)
117	Sheet Metal Perimeter Foundation	2002	Nomination (NOVA)
118	Talking Aerial Work Platform	2002	Nomination (NOVA)
119	All-In-One Street Trench-Milling	2002	Nomination (NOVA)
120	Interlocking Mortarless Brick Siding	2002	Nomination (NOVA)
121	Restorative Ionized Air Wash	2002	Nomination (NOVA)
122	Reinforced Concrete Tied-Arch Truss	2002	Nomination (NOVA)
123	Recycled Plastic Composite Crossties	2002	Nomination (NOVA)
124	Nawic K-12 Construction Education	2002	Nomination (NOVA)
125	Construction Congestion Cost (CO3)	2002	Nomination (NOVA)
126	Automatic Self-Climbing Formwork	2002	Nomination (NOVA)
127	Ice Blast Cleans Surfaces	2002	Nomination (NOVA)
128	Economical Bridge Rehabilitation Using Composites	2002	Nomination (NOVA)
129	Multi-Span Suspended Bridge Platform	2002	Nomination (NOVA)
130	Ground Penetrating Radar	2002	Nomination (NOVA)
131	Electric Mini-Excavator	2002	Nomination (NOVA)
132	Residential Utility Trenching Machine	2003	Nomination (NOVA)

133	Military Tank Proof Load Testing Determines Capacity of Bridges	2000	Nomination (NOVA)
134	Fire Resistant Insulation Composition for High Temperatures	2000	Nomination (NOVA)
135	VEAP Energy Absorbing Reactive Guardrail System	1999	Nomination (NOVA)
136	Unburnt Fine Fireproof Concrete Made of Industrial By-products	1999	Nomination (NOVA)
137	Tru-Frame™ Special Steel Truss Moment Framing System	1999	Nomination (NOVA)
138	Superdeck™-- All Composite Pultruded Bridge Deck	1999	Nomination (NOVA)
139	SNAP TITE™-- Composite Column Reinforcement System	1999	Nomination (NOVA)
140	Reactive Powder Concrete	1999	Nomination (NOVA)
141	Rapid Load Non-destructive Testing Of Structures	1999	Nomination (NOVA)
142	ProjectWise Integrated World-Wide Web Access	1999	Nomination (NOVA)
143	PerSpective™ Streamlines Design-Build Proposal Process	1999	Nomination (NOVA)
144	Statnamic Lateral Testing of Dynamic Loading On	1999	Nomination (NOVA)
145	Removal of Jammed Power - Telephone Utility Cables	1999	Nomination (NOVA)
146	Information Delivery Software For Geospatial Construction Site Data	1999	Nomination (NOVA)
147	GRAM High Performance Spun Concrete Columns	1999	Nomination (NOVA)
148	Gang-Ease Electric Gang Box Cover and Positioning Devices	1999	Nomination (NOVA)
149	EcoSystem™-- Affordable, Environmentally-Friendly Elevators	1999	Nomination (NOVA)
150	Document Manager for Construction Site Documents	1999	Nomination (NOVA)
151	Student Team Consulting for Construction Industry Clients	1999	Nomination (NOVA)
152	Join America's Build Team National Teleconference On Construction Careers	1999	Nomination (NOVA)
153	Pre-Cast Arched Wall Panels For Underground Library	1999	Nomination (NOVA)
154	AMIR - Asphalt Multi-Integrated Roller for Asphalt Pavement Compaction	1999	Nomination (NOVA)
155	Segmental Precast Floating Pontoon Draw Span Bridge	1999	Nomination (NOVA)
156	ULTRASCREEN: Sight and Sound Barrier	2005	CII ECT
157	Super Therm - Ceramic Paint Insulation	2005	CII ECT
158	FRP Rebar	2003	CII ECT
159	FRP Rebar	2003	CII ECT
160	FRP Rebar	2003	CII ECT
161	Substiwood™ - Concrete Lumber	2001	CII ECT
162	Bone-shaped Short Fiber Composite	2001	CII ECT
163	SIMCON: Slurry Infiltrated Mat Concrete	2001	CII ECT
164	Alternative Material Dowel Bars for Rigid Pavement Joints	2001	CII ECT
165	Alternative Material Dowel Bars for Rigid Pavement Joints	2001	CII ECT
166	Snap Joint Technology for Composite Structures	2001	CII ECT
167	Snap Joint Technology for Composite Structures	2001	CII ECT
168	CP40: FRP/Concrete Piles	2000	CII ECT
169	Superpave System	2000	CII ECT
170	Superpave System	2000	CII ECT
171	Modular FRP Composite Bridge Deck	2000	CII ECT
172	Carbon Fiber Reinf. Polymer (CFRP) Laminates for Structural Strengthening	2000	CII ECT
173	New Structural Material - Fiber Reinforced Plastics	2000	CII ECT
174	Polymer Concrete Pipes	2000	CII ECT
175	Recycled Plastic Composite Railroad Crossties	2000	CII ECT
176	Low Temperature Concrete Admixture	2004	CII ECT
177	Low Temperature Concrete Admixture	2004	CII ECT
178	Steel-Free Concrete Bridge Deck	2001	CII ECT
179	Pavemend - Ceracrete Rapid Repair Products	2002	CII ECT

180	Pavemend - Ceracrete Rapid Repair Products	2002	CII ECT
181	Surtreat - Concrete Restoration & Protection System	2001	CII ECT
182	Precast Inverted T-Beam	2001	CII ECT
183	Prepacked Shotcrete Admixture : Spray-Con WS	2001	CII ECT
184	Italgrip System	2001	CII ECT
185	Pothole Repairing Compound : Bondade TCU-31	2001	CII ECT
186	Conductive Concrete	2003	CII ECT
187	Smart Concrete	2000	CII ECT
188	Reactive Powder Concrete	2000	CII ECT
189	MELLOSE non-dispersible Underwater Concrete Admixture	2000	CII ECT
190	Segmental Precast Floating Draw Span	2000	CII ECT
191	Digital Hardhat System	2004	CII ECT
192	Digital Hardhat System	2004	CII ECT
193	Stay-In-Place (SIP) Formwork	2003	CII ECT
194	Stay-In-Place (SIP) Formwork	2003	CII ECT
195	Stay-In-Place (SIP) Formwork	2003	CII ECT
196	Electrochemical Chloride Extraction	2001	CII ECT
197	Electrochemical Chloride Extraction	2001	CII ECT
198	Electrochemical Chloride Extraction	2001	CII ECT
199	Unpaved Road Stabilizer	2001	CII ECT
200	Paslode - Cordless Finish Nailer	2001	CII ECT
201	FLOAT-IN DAM - "In the Wet" Construction Methods	2001	CII ECT
202	FLOAT-IN DAM - "In the Wet" Construction Methods	2001	CII ECT
203	DIS Seismic Isolater	2001	CII ECT
204	Movax Robotic: Hydraulic Vibratory Pile Driver	2000	CII ECT
205	BladePro: 3D Automatic Grade Control System	2000	CII ECT
206	Shaking Table System for Geotechnical Centrifuge	2000	CII ECT
207	Shaking Table System for Geotechnical Centrifuge	2000	CII ECT
208	AR2000 Super Recycler	2000	CII ECT
209	Asphalt Paver Engineering Control Systems	2000	CII ECT
210	Asphalt Paver Engineering Control Systems	2000	CII ECT
211	AMIR: Asphalt Multi Integrated Roller	2000	CII ECT
212	3D-MC Three Dimensional Machine Control	2000	CII ECT
213	3D-MC Three Dimensional Machine Control	2000	CII ECT
214	Hot In Place Asphalt Recycling (HIPAR)	2001	CII ECT
215	Hot In Place Asphalt Recycling (HIPAR)	2001	CII ECT
216	Hot In Place Asphalt Recycling (HIPAR)	2001	CII ECT
217	Soundless Chemical Demolition Agents	2000	CII ECT
218	Soundless Chemical Demolition Agents	2000	CII ECT
219	Soundless Chemical Demolition Agents	2000	CII ECT
220	Lateral STATNAMIC Testing	2000	CII ECT
221	Deep Mixing Method for Ground Improvement	2004	CII ECT
222	Kwik-Kap Metal Roof Fastener Seals	2001	CII ECT
223	Post-tensioned Steel Structure	2003	CII ECT
224	Post-tensioned Steel Structure	2003	CII ECT
225	MMFX Microcomposite Steel (MMFX2)	2002	CII ECT
226	Friction PendulumTM - Seismic Isolation Bearings	2001	CII ECT

227	Bridge Lock-up Device System	2001	CII ECT
228	Precast Hybrid Moment Resistant Frames	2000	CII ECT
229	Precast Hybrid Moment Resistant Frames	2000	CII ECT
230	Pipeman:Safety in Trenches	2000	CII ECT
231	Pipeman:Safety in Trenches	2000	CII ECT
232	Pipe Structural Reliability Evaluating System	2001	CII ECT
233	Load Test	--	Other

9.4 Case Study Sample Projects

The following list contains the 20 projects that were randomly selected to be case studies from the 40 award-winning and regular projects.

Project ID	Location	Date Completed	Type	Award (if applicable)
1	Las Angeles, CA	2002	Building (Cathedral)	ASCE OPAL award
2	Seattle, WA	2000	Building - Museum	Listed in GreatBuildings.com
3	Oregon Coast	2005	Residential	Green Building of the Year (2005)
4	San Diego, CA	2005	Parking Structure	DBIA National Design-Build Award (2005)
5	Memphis, TN	2004	Institutional	Technology Leap Award Winner (buildings.com)
6	Dearborn, MI	2003	Industrial/ Manufacturing	NOVA and AIA Sustainability Awards (2003)
7	Boston, MA	2003	Tunnel	NOVA recognized as a 'first' technique
8	Miramar, FL	2006	Hospital Structure	ASCE Regional Project of the year
9	Chicago, IL	2004	Residential Commercial Building	Residential/Housing Project of the Year (2004)
10	Warner Robins, GA	2006	Commercial Building	2006 Project Innovations recipient
11	Chicago, IL	2003-05	Commercial Building	--
12	Arlington, TX	2003-05	Fine Arts building	--
13	Lee County, FL	2003-05	Elementary School	--
14	Kennesaw, GA	2003-05	Community Center	--

15	Baltimore, MD	2003-05	Art Museum	--
16	New York, NY	2003-05	Zoo Building	--
17	Key West, FL	2003-05	Courthouse	--
18	Jacksonville, FL	2003-05	Apartment Building	--
19	Atlanta, GA	2003-05	Office Building	--
20	Las Vegas, NV	2003-05	Pedestrian Bridge	--

9.5 Case Study Interview Template

The following questions were used as a template to structure the interviews conducted as part of the case studies.

INTERVIEW QUESTIONS - DEMOGRAPHICS

	Category	Response
1	Name	
2	Position	
3	Years of experience	

INTERVIEW QUESTIONS - ORGANIZATIONAL QUESTIONS

	Category	Indicator (Organization in general and this project)	Yes	No	1	2	3	4	5
1	Upper mgmt support	Personal involvement or interest							
2	Upper mgmt support	Time allowed to explore ideas							
3	Upper mgmt support	Marketing							
4	Upper mgmt support	Part of organization strategy							
5	Upper mgmt support	To what extent is innovation in your organization's mission							
6	Upper mgmt support	To what extent is innovation in your organization's innovation plan							
7	Upper mgmt support	To what extent is innovation in your organization's budget							
8	Upper mgmt support	To what extent does your organization hold innovation meetings							
9	Communication	To what extent is communication open							
10	Communication	To what extent is communication cross-discipline							
11	Communication	To what extent is communication encouraged							
12	Communication	To what extent is communication unilateral							
13	Recognition	Do you have formal mechanisms to recognize individuals							
14	Recognition	Do you have formal mechanisms to recognize teams							
15	Recognition	Do you have formal mechanisms to recognize subcontractors							
16	Lessons Learned	Do you have formal mechanisms to capture lessons learned							
17	Lessons Learned	Do you have formal mechanisms to disseminate lessons learned							
18	Lessons Learned	Do you have formal mechanisms to disseminate innovations							
19	Lessons Learned	Do you implement lessons learned on future/subsequent projects							
20	R&D	To what extent do you perform R&D in general							
21	R&D	To what extent do you consider budget in R&D							
22	R&D	To what extent was there time allowed for R&D							
23	R&D	To what extent was R&D supported by your firm							

INTERVIEW QUESTIONS - PROJECT QUESTIONS

Project Characteristic	
Method of project delivery	
Structure of design-build, if applicable	

Project Scope (difficulty of work/uniqueness/complexity)	
Total project budget	
Project Type (new, repair, demo, etc.)	
Public or Private	

	Category	Indicator	Yes	No	1	2	3	4	5
1	Proj. Delivery	To what extent was the project integrated							
2	Proj. Delivery	To what extent did multiple firms work as a team							
3	Owner	To what extent was the owner involved or interested in innovation							
4	Owner	To what extent did the owner allow time to develop innovative ideas							
5	Owner	To what extent was innovation a project objective of the owner							
6	Owner	To what extent did the owner include innovation in the budget							
7	Collaboration	To what extent did people work in groups							
8	Outcomes	Please rate the overall project productivity							
9	Outcomes	Please rate the overall project quality							
10	Outcomes	Please rate the overall project safety							
11	Champion	To what extent was there a champion(s)							
12	Competition	To what extent was there competition for the project							

INTERVIEW QUESTIONS – INNOVATION SUCCESS

Metric	
Number of successful innovations	
Number of unsuccessful innovations	
Number of patent submissions	
Development of "trade secrets"	
Rating of "innovativeness" of the project (1-10)	
Number of innovations used on subsequent projects	

	Category	Indicator: To what extent….	YES	NO	1	2	3	4	5
1	Innovation Success	Did innovation contribute to profit							
2	Innovation Success	Did innovation contribute to schedule performance							
3	Innovation Success	Did innovation contribute to quality improvement							
4	Innovation Success	Did innovation contribute to increased productivity							
5	Innovation Success	Did innovation contribute to improved safety							
6	Innovation Success	Did innovation contribute to market share or reputation							
7	Innovation Success	Have the innovations been used on subsequent projects							
8	Innovation Success	Did innovation contribute to the overall owner satisfaction							

OPEN-ENDED INTERVIEW QUESTIONS

1. Please describe the upper management's support of innovation on this project.
2. Please describe the communication between firms on this project.

3. Please describe the recognition of individuals and teams for their innovation achievement and effort.
4. Please describe how lessons learned were captured for this project. Also, how were lessons learned on old projects used on this project?
5. Please describe R&D efforts for innovation on this project.
6. To what extent did the project delivery method enable or impede innovation.
7. Please describe the Owner's involvement in innovation.
8. Please describe the results of innovative efforts.
9. Please describe the impact of a champion on innovation within a project.
10. Please describe the impact of competition on innovation within a project.

9.6 Validation Cover Letter and Questionnaire

The following questionnaire was distributed to those people who participated in the initial stages of the research and who were asked to provide input on the validation of the study findings.

Dear _______________,

With your help the Oregon State University research team has collected a significant amount of data on the topic of innovation within the architecture, engineering and construction (A/E/C) industry. We have compiled our findings and are assembling a report which includes a set of guidelines for energizing innovation.

We are sending this email to ask for your assistance in validating our results. We have created a survey that presents our list of guidelines for general innovation, idea generation, creating the opportunity for implementation of ideas and diffusion of innovation. The survey asks you to rate the effectiveness of the various organizational elements, best-practices and characteristics that we have identified in our study. We hope that you will take the time to complete the survey as you have played an integral role in the development of our findings.

The survey is intended to be completed in 10 to 20 minutes depending on the level of detail provided by the respondent. The survey can be found at the following link: http://web.engr.oregonstate.edu/~hallowem/Validation.html

In appreciation for your continued assistance we will provide you with both the results of this survey and the final report once they have been completed. As always your response will be kept confidential. In other words, our report will never include the names of individuals or companies. If you have any questions you may direct them to John Gambatese at john.gambatese@oregonstate.edu or Matthew Hallowell at hallowem@onid.orst.edu

Thank you for your time and effort!

John Gambatese and Matt Hallowell

Thank you for providing your insight in the previous phase of this research. Our research team has conducted several surveys and case studies in an effort to create guidelines for energizing innovation in the A/E/C industry. We are asking you to review our findings, provide some comments and rate the effectiveness of the guidelines. Please answer the following questions, providing as much detail as possible where requested. When you have finished answering the questions, submit your response using the "Submit" button at the end of the survey. Please do not click "ENTER" as it will prematurely end the survey!

Please respond to only those questions that you feel qualified to answer. Your individual responses will be kept confidential and not be used for anything unrelated to this study. Summarized data will not identify individual participants or companies.

Any information that you can share is greatly appreciated! Your response will become a vital component of our research project and ultimately benefit the A/E/C industry. In appreciation for completing the survey, we are happy to send you a summary of the survey results.

If you have any questions about this survey or about the research project in general, please do not hesitate to contact us at: hallowem@onid.orst.edu or john.gambatese@oregonstate.edu

Personal Information

Name:

Email:

Definition of Innovation

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. Further, the term innovation is distinguished from invention, in that invention requires a detailed design or physical manifestation that is novel when compared to the existing arts—whether the invention is actually employed in practice or not. Innovation, however, includes application of the invention and the diffusion throughout the A/E/C industry. Additionally, innovation may be the application of a method that is within the realm of the existing arts but is just new to the organization adopting it.

Innovation

Please rate the effectiveness of the following elements in their ability to enhance innovation on projects and within firms. In the comment field please indicate specifically how you believe the element will impact innovation and any best practices that you are aware of.

Element	**No Impact**	**Low**	**Moderate**	**Significant**	**Extreme**
Project team collaboration	☐	☐	☐	☐	☐
Integrated functions of project teams	☐	☐	☐	☐	☐
Overlapping phases	☐	☐	☐	☐	☐
Strategic project team selection	☐	☐	☐	☐	☐
Employee recognition	☐	☐	☐	☐	☐
Work environment	☐	☐	☐	☐	☐
Communication/interaction within one firm	☐	☐	☐	☐	☐
Communication/interaction among multiple firms	☐	☐	☐	☐	☐
Diversity of the project team	☐	☐	☐	☐	☐
Innovation champion	☐	☐	☐	☐	☐
Owner investment/commitment	☐	☐	☐	☐	☐
Upper management support	☐	☐	☐	☐	☐
R&D efforts	☐	☐	☐	☐	☐
Training and education of employees	☐	☐	☐	☐	☐
Lessons learned/knowledge management	☐	☐	☐	☐	☐
Other: ______	☐	☐	☐	☐	☐
Other: ______	☐	☐	☐	☐	☐

Idea Generation

Please rate the impact of the following practices on the ability of a firm to generate new ideas on a construction project. In the comment field please describe how the practice influences idea generation and any best practices that you are aware of.

Practice	No Impact	Low	Moderate	Significant	Extreme
Project team collaboration	☐	☐	☐	☐	☐
Integrated functions of project teams	☐	☐	☐	☐	☐
Project delivery method	☐	☐	☐	☐	☐
Overlapping phases	☐	☐	☐	☐	☐
Constructability reviews	☐	☐	☐	☐	☐
Value engineering efforts	☐	☐	☐	☐	☐
Project team selection	☐	☐	☐	☐	☐
Employee recognition	☐	☐	☐	☐	☐
Allowing time for creativity/exploration	☐	☐	☐	☐	☐
Ability of lower level employees to communicate with upper management	☐	☐	☐	☐	☐
Active communication	☐	☐	☐	☐	☐
Face-to-face communication	☐	☐	☐	☐	☐
Having a centralized office for the project	☐	☐	☐	☐	☐
R&D Budget	☐	☐	☐	☐	☐
R&D Meetings	☐	☐	☐	☐	☐
Time allocated for R&D	☐	☐	☐	☐	☐
Employees dedicated to R&D	☐	☐	☐	☐	☐
Diversity of the project team	☐	☐	☐	☐	☐
Training and education of employees	☐	☐	☐	☐	☐
Innovation champion	☐	☐	☐	☐	☐
Other: ______	☐	☐	☐	☐	☐
Other: ______	☐	☐	☐	☐	☐

Opportunity for Implementation of Ideas

Please rate the impact of the following project characteristics on the opportunity to implement new ideas on a construction project. In the comment field please describe how the characteristic creates the opportunity for implementation and any best practices that you are aware of.

Project Characteristic	No Impact	Low	Moderate	Significant	Extreme
Owner investment/commitment	☐	☐	☐	☐	☐
Owner's commitment of resources for innovation efforts	☐	☐	☐	☐	☐
Innovation as a goal of the Owner	☐	☐	☐	☐	☐
The innovation vision of the Owner	☐	☐	☐	☐	☐
Allowing time for creativity/exploration	☐	☐	☐	☐	☐
Ability of lower-level employees to communicate with upper management	☐	☐	☐	☐	☐
Upper management support and commitment to innovation	☐	☐	☐	☐	☐
Innovative visionaries within the firm	☐	☐	☐	☐	☐
Not being risk averse	☐	☐	☐	☐	☐
Presence of a champion/sponsor for innovation	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐

Diffusion

Please rate the impact of the project characteristics practices on the opportunity to implement new ideas on a construction project. In the comment field please describe how the characteristic creates the opportunity for implementation and any best practices that you are aware of.

Project Characteristic	No Impact	Low	Moderate	Significant	Extreme
Lessons learned/knowledge management	☐	☐	☐	☐	☐

program					
Communication among firms	◯	◯	◯	◯	◯
Communication among various project teams within the firm	◯	◯	◯	◯	◯
Training and education of employees	◯	◯	◯	◯	◯
Other:	◯	◯	◯	◯	◯
Other:	◯	◯	◯	◯	◯

Additional Information

Please provide any additional comments about innovation in the A/E/C industry below.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE! YOUR INPUT IS VERY VALUABLE TO THE RESEARCH PROJECT!

Submit

9.7 Innovative Products Study Sample

The following list of products shows those products developed by the firms that responded to the innovative products survey.

	Innovative Product
1	Hydraulic Excavator Personal Simulator
2	ArchPanel
3	Last Planner System
4	Temporary Flood Barrier
5	FlexLock Wall System
6	Composites
7	Portable concrete washout container
8	Core Clear horizontal reinforcing
9	Project Information Management System
10	Fast Fusion
11	Multi-Ripper Products
12	Project Rework Reduction Tool
13	Turner Knowledge Network
14	Anchorpanel Perimeter Foundation System
15	FRP Rebar
16	Bid Express
17	Shoulder Wedge Maker
18	Electronic document dissemination
19	Pneumatic Capsule Pipeline
20	Open cell Bulkheads spin fin piles wave barriers driven piles in permafrost
21	Lightning Switch
22	Restorative Ionized Air Wash
23	Electronic Project Control System (e-PCS)
24	WetSep Wastewater Filtration System
25	ePCS
26	LeakfinderRT Leak Noise Correlator
27	Performance-based car park ventilation design
28	PVC Stay-in-place forming system
29	Pipeman Jr/Sr.
30	SoniCaliper
31	MMFX Steel
32	Float-in/lift in to the wet cement
33	Lightweight high-strength concrete
34	Deep Mixing Method

9.8 Case Study Summaries

The following pages provide summary information about the case study projects. Information that could be used to identify the project has been omitted to preserve the anonymity of the project as much as possible.

Case Study Project A

Location: Northwest
Type: Residential structure
Class: New facility
Project Delivery Method: Negotiated design-build
Funding Source: Private
Designation: Award-winning project

Entities Interviewed
Owner
Designer
Representative of the Department of Energy

Description of the Project
Completed in 2005, this project is a 3-bedroom, 2.5 bath, 2,268 square foot residential home built in the Northwest. According to the designer, the project owner requested "a small home that would be healthy to live in with a dramatically reduced impact on the environment." The owner required the project team to research and incorporates new eco-friendly materials, systems and layouts. By researching, incorporating and creating "green" innovations this project is potentially the most environmentally friendly structure in the United States. The home energy rating system HERS rating is 94.0 making it 58% more efficient than the Energy Code required. The home generates more energy than it uses on an annual basis.

Innovations on the Project
Collection of all of the most "green" elements into one structure including Durisol block, vegetative roof, few interior walls, clerestory windows, "short basement" and insulating concrete forms and solar panels. This green system was unlike no other, with all components working in concert.

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 ft deep cores in the basalt bedrock to store the heat until winter. During the winter the heated water is recovered. The cost of this system was $11,000.

Enablers for Innovation
The interviewees identified the following enablers of innovation:

- Owner's innovative vision
- Personal involvement and expertise of the Owner
- Time to explore new ideas
- Strategic selection of the project team
- Integrated functions
- Face-to-face meetings
- R&D before the project began

Barriers to Innovation

The interviewees identified the following barriers to innovation:

- Some innovations required trial and error which were time consuming and expensive (high risk)
- Innovation required deviating from standard custom and practice. People can be uncomfortable with that
- There were no innovation-specific meetings
- Low emphasis on employee recognition
- Innovations hurt productivity
- LEED residential was not completed at the time the project was built

Outcomes of Innovation

The owner satisfaction on this project was very high and the home has been as energy efficient as expected. The architect stated that he believed that the innovation success on this project was the main reason for the emerging success of his firm. Both entities believed that the project increased marketability of the firms and other firms of long-term success. Other impacts include:

- Contribution to profit
- Market share and reputation of all firms
- Ability to use innovations on subsequent projects

Diffusion of Innovation

One of the objectives of the owner was to diffuse the green innovations throughout the industry in order to maximize the positive impact on the environment. The owner currently holds tours of the home. Also, before groundbreaking the project team hosted a day-long training session on green building techniques learned during the project. Over 50 professionals attended the meeting/training.

Lessons Learned

- It takes significant time, energy and a strong commitment to the innovative vision in order for innovation to thrive.
- Having an owner that knows the right questions to ask was a huge benefit.

Case Study Project B

Location: Midwest
Type: Industrial and Manufacturing
Class: New facility
Project Delivery Method: CM and DB
Funding Source: Private
Designation: Award winning project

Entities Interviewed
Owner
Designer
Construction Manager
Contractor

Description of the Project
According to the AIA website, this project, "is by far the most ambitious sustainable project ever, proving for the first time that sustainability can indeed be implemented on a very large-scale." This project is now the symbol of the "Sustainable Revolution", the result of a comprehensive and significant redevelopment of the existing brownfield site.

In order to construct the $2 billion facility a dream team of environmental, development and manufacturing specialists and recruited noted sustainability architect. Their redevelopment plan incorporated a number of lean manufacturing and environmental features to make the project a healthy, productive, supportive work environment.

The new facility features world-class flexibility, with assembly lines capable of handling three different product platforms and nine different models. Finished product storage space has been reduced by 50% inside and outside the plant since 90% of the products produced are shipped the same day.

Innovations on the Project
The following innovations were developed during this project:

- The world's largest ecologically inspired living roof, about 500,000 square feet, dramatically affects the local area watershed by holding several inches of rainfall.
- Phytoremediation: the use of natural plants throughout the grounds rids soil of contaminants.
- Swales: shallow green ditches seeded with indigenous plants improve storm-water management.
- Porous paving filters water through retention beds with two to three feet of compacted stones, helping manage storm-water runoff.
- Renewable energy sources such as fuel cells.

Enablers for Innovation
No enablers were identified.

Barriers to Innovation
Project communication levels were fairly low making it difficulty to gain buy-in on innovations. Also the lack of communication made some potential innovation unsuccessful due to constructability issues. There was also a very low emphasis on employee recognition.

Outcomes of Innovation
The sustainability success on the project improved the project's quality significantly. These innovations required compromising the project's budget and schedule performance. Now that the facility is operational, there is very little impact on the environment. The green roof, energy reduction, recycling and landscape systems are performing as expected. Other measurable outcomes included:

- Profit
- Quality
- Market share and reputation
- Owner satisfaction

Diffusion of Innovation
A unique feature of this project is the visitor's center which depicts the manufacturing and environmental innovations at the facility close up. The first thing visitors see inside the center is a massive mural, displayed above the entrance to The Legacy Theater. It depicts the innovations generated in the construction of the center and honors the generations of people who made the facility an icon of 20th century manufacturing.

The project participants believed that, despite the marketing of the innovations and free communication with other firms in the construction industry, diffusion has been very low. They believed that the project was so unique that the innovations developed on this project would be difficult to transfer to another.

A project website is also available that identifies and describes each project innovation. Included are descriptions of each innovation, anecdotal information from each entity involved with the project regarding the development of each innovation, a project description and awards received.

Lessons Learned
There were no lessons learned identified for this project identified through the case study research.

Case Study Project C

Location: Southwest
Type: Bridge (foot traffic)
Class: New facility
Project Delivery Method: Design-bid-build
Funding Source: Public
Designation: Non award-winning project

Entities Interviewed
Owner
General Contractor (2)

Description of the Project
A new pedestrian bridge across a major thoroughfare provides safe movement for walkers in addition to relieving traffic congestion created from the mix of large numbers of pedestrians and vehicles. The pedestrian bridge features a wide, straight path and glass barrier walls supported by steel beams. The glass walls create aesthetically pleasing bridge structures that compliment the surroundings. Pedestrians may access the elevated corridors by escalators, elevators or stairs. An elegant, domed rotunda is found at the south end of the bridge. The structure features a large, circular tile floor in hues of cream and sienna. The rotunda affords pedestrians the opportunity to view the visually spectacular downtown area.

Innovations on the Project
Those interviewed cited beneficial QC/QA procedures and the integration of design and inspection as unique features of the project. In addition, RFI's were expedited through the use of new software.

Enablers for Innovation
The interviewees identified the following enablers to innovation:

- Upper management support
- Education of the employees
- Communication within the firm
- Communication among members of the project team
- Research and development efforts
- Design-bid-build project delivery method
- Integrated functions

Barriers to Innovation
The interviewees identified the following barriers to innovation:

- Local, state, and federal codes
- Adjacent construction
- Lack of resources allocated by the Owner to innovation
- Simplicity of the project

Outcomes of Innovation

Innovation was linked to improvements in the following:

- Quality improvement
- Profitability of the firm
- Project budget
- Increase in market share for the project participants
- Increased productivity

Diffusion of Innovation
No diffusion was identified for this project through the case study interviews.

Lessons Learned
The builder noted the following lessons learned:

- Unknown utilities caused delays. Vector analysis is not useful for unknown utilities. To prevent delays, more design effort in the beginning of the project would have helped.
- Dealing with many high profile owners can be difficult. On this project they needed extensive research of business owners. Also, signing agreements on design features before construction would have helped to prevent delays.

Case Study Project D

Location: West
Type: Commercial building
Class: New facility
Project Delivery Method: Design-build
Funding Source: Private
Designation: Award-winning project

Entities Interviewed
DB Firm
Material supplier

Description of the Project
This $95 million, pre-cast concrete private structure on the West Coast involved fifteen innovations of varying effectiveness. According to an article written by Dr. Robert Englekirk for the PCI journal, "at 39 stories and 420 ft (128 m) high, (this project) is the tallest concrete structure in addition to being the tallest precast, prestressed concrete framed building in Seismic Zone 4 (a double record). 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 this seismic ductile frame includes post-tensioning and high strength reinforcing steel. All this represents a major milestone in the development of precast/prestressed concrete. The building is basically an apartment complex, although the lower floors accommodate retail space, vehicle parking and recreational amenities. This article presents the design considerations, construction highlights, research and development, and code approval process that led to the realization of this structure."

Innovations on the Project
The following innovations were identified for this project:
- Structural framing system
- Architectural/structural integration
- Tubular stressed frame
- Pre-cast assembly techniques
- Flying form support for beams
- Strand insert pipes
- Stressing table
- Round the corner stressing
- Grouting of joints
- Slab stressing blockouts
- Cast-in-place DDC
- Rebar alignment access blockouts
- Grouting of ducts
- Stressing head covers
- Grouting bin

Enablers for Innovation

The following enablers were identified:

- Integrated project team functions
- Phase overlap
- Upper management support
- Open communication
- Innovation sponsor/champion

Barriers to Innovation

The following factors impeded innovation on this project:

- Lack of Owner vision
- Lack of resources allocated by the Owner
- Lack of an employee recognition project
- No formal mechanism for lessons learned
- Unilateral communication within participating firms
- Lack of a budget and time for R&D

Outcomes of Innovation

Most of the benefits of the precast concrete innovations were measureable impacts on the project budget, schedule, quality, and owner satisfaction. Most benefits were direct benefits to the builder who used precast concrete innovations to compress the construction timeline and to improve productivity and budget performance. Also, project members mentioned an improvement in market share and reputation as a benefit of the project innovation.

Diffusion of Innovation

Innovations developed by the builder and the precast concrete manufacturer have been used on almost every large-scale precast concrete construction project.

Lessons Learned

The lessons learned were not captured through any formal knowledge management system identified through interviews. Literature has been created and reports have been published on the project in informal journals. Each of the most influential innovations has been described and published in trade publications such as ACI.

Case Study Project E

Location: Southeast
Type: Residential structure
Class: New facility
Project Delivery Method: Design-bid-build
Funding Source: Private
Designation: Non award-winning project

Entities Interviewed

Architect
General Contractor

Description of the Project

This $18 million residential structure built in the Southeast was a simple commercial residential development project. The project owners had the simple goal of creating a basic, but attractive residential structure that was built quickly for the lowest possible price. Midway through the project the owner firm changed. The new owner made $300,000 in changes mid-construction. During the construction of the project, large amounts of rain from a hurricane caused minor flooding.

Innovations on the Project

All innovations identified by interviewees were architectural features in nature. These architectural achievements did not qualify as innovations according to the definition set for this study.

Enablers for Innovation

Despite the lack of innovation on this project, the following factors were identified as enablers:

- Innovation as a goal of the Owner
- Champion for an unsuccessful innovation
- Upper management support for generation of new ideas
- R&D efforts supported by the construction firm

Barriers to Innovation

The following barriers were identified for innovation:

- Lack of cross-discipline communication
- Unilateral communication
- Lack of employee recognition programs
- Lack of innovation meetings
- Lack of resources allocated to innovation by the Owner
- Design-bid-build project delivery
- Multiple firms did not work as a team
- No innovation budget
- No time allotted to explore new ideas

Outcomes of Innovation
Since there were no identifiable innovations on this project, there were no reportable impacts on project performance.

Diffusion of Innovation
Not applicable since there were no identifiable innovations.

Lessons Learned
To improve innovation, contractors should bid on projects that are associated with progressive, innovative, and challenging owners.

Case Study Project F

Location: Northwest
Type: Museum
Class: New facility
Project Delivery Method: Design-bid-build
Funding Source: Private
Designation: Award-winning project

Entities Interviewed
General Contractor
Supplier

Description of the Project
This project is a museum of music history founded by a prominent executive located in the Northwest. Using a unique structural design and construction procedure, the project team - comprised of nearly 100 architects, engineers, contractors, and subcontractors on eight coordination teams - worked in concert to make the $240 million, 140,000-square-foot museum. The American Society of Engineers webpage describes the project as “a project so geometrically complex it required an entirely new approach using a virtual model from concept through construction.”

Through an extensive use of 3D computer imaging software, a very complex structural system was designed, based on building techniques similar to those used in aviation and nautical construction. This technology allowed the architects to design a first-of-its-kind, non-symmetrical building.

Innovations on the Project
An elaborate system of 5-inch diameter steel piers on the building’s interior attach to the frame to support the 3,000 steel and aluminum panels, comprised of 21,000 individually shaped panels, as the building’s outermost diaphragm.

One of the project’s unique features is the invention of a new “organic” structure based on the concept of the human rib cage. Up to that point, 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 girder fabrication methods.

3D imaging during the design of the project and unique translation to 2D drawings were first-of-their kind. 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.

Curved members were created by specialty manufacturers who used specially-designed equipment for creating structural and architectural elements.

Enablers for Innovation

The following innovations were identified:

- Upper management support
- Time allowed to explore new ideas
- Innovation as a part of the organizational strategy for the project
- Communication among project team members
- Integrated functions
- Lessons learned program in real-time
- R&D efforts
- Owner investment of resources in innovation
- Owner's allowance of time to explore new ideas
- Innovation budget
- Owner's innovative vision
- Project team collaboration
- Champion for each innovation

Barriers to Innovation

The following factors impeded innovation:

- No formal methods to recognize employees or subcontractor's special efforts
- Unilateral communication
- No budget for R&D
- Limited time allotted for R&D

Outcomes of Innovation

This project was a finalist for the 2002 Outstanding Civil Engineering Achievement (OCEA) Award by the American Society of Civil Engineers (ASCE). Other direct benefits included:

- Improved productivity
- Quality and owner satisfaction
- Safety
- Profit
- Schedule performance

Diffusion of Innovation

Project innovations were used on subsequent projects and transmitted through formal lessons learned (knowledge management) tools developed by the contractor and designers.

Lessons Learned

Most lessons learned were technical in nature.

Case Study Project G

Location: Southeast
Type: Community Center
Class: Renovation
Project Delivery Method: Design-build
Funding Source: Public
Designation: Non award-winning project

Entities Interviewed
Owner
Design-build firm

Description of the Project
This project was a $2 million renovation project. The public facility is a community center with a pool, basketball courts, and meeting rooms. The structure was completed on an expedited schedule with many change orders.

Innovations on the Project
The innovations identified by the interviewees were all related to the use of design-build in publicly-funded projects. According to the definition of innovation set for this project, the typical design-build project delivery arrangement does not represent an innovation, even on publicly-funded projects since it is already being used regularly throughout the U.S.

Enablers for Innovation
The following factors were identified as enablers for innovation despite the lack of innovation on the project:

- Project delivery method
- Integrated functions
- Upper management support
- Open communication

Barriers to Innovation
The following factors impeded innovation on this project:

- Lack of innovation as part of the organizations strategy, mission, business plan and budget
- No formal mechanism for recognizing employees or subcontractors
- No R&D, no R&D budget, time for R&D, etc.
- No innovation budget
- No innovation vision of the Owner
- No support or time investment for innovation from the Owner

Outcomes of Innovation
Not applicable given the lack of innovations.

Diffusion of Innovation

Not applicable given the lack of innovations.

Lessons Learned

Design-build allowed the opportunity for compressing the schedule and delivering the project to meet the owner's needs (in comparison to typical public DBB arrangements).

Case Study Project H

Location: East Coast
Type: Museum
Class: Renovation
Project Delivery Method: Design-bid-build
Funding Source: Public
Designation: Award-winning project

Entities Interviewed
Owner
Designer
General Contractor

Description of the Project
The project's website describes the project as a "35,000-square-foot main building that combines an elliptical, three-story, historic industrial building with extensive new architecture to contain six galleries, filled with art exploring one central exhibition theme at a time. The central stairway, balustrade, and garden gates were beautifully hand cast."

This renovation project took place in an urban environment with heavy traffic and limitations posed by adjacent structures. In order to demolish or "gut" the building the project team was required to shore the structure and brace the walls from the inside. Most innovations stemmed from solving this unique problem.

Innovations on the Project
The only major innovation was the use of internal shoring to brace the interior walls as the beams and internal elements were removed. The project team felt as if this one the first internal bracing designs utilized in this fashion.

Enablers for Innovation
The following were identified as factors that facilitated innovation:

- Owner vision and involvement
- Upper management support
- Open communication
- Cross-discipline communication
- Integrated functions (designer and builder)
- High level of competition for the project

Barriers to Innovation
The following factors impeded innovation:

- No employee or subcontractor recognition programs/efforts.
- No investment, interest, or support for R&D

Outcomes of Innovation

In addition to being able to demolish the interior of the original building, the use of internal shoring impacted the following:

- Schedule performance
- Productivity
- Market share and reputation of the builder
- Overall Owner satisfaction

Diffusion of Innovation

The contractor and designer conducted meetings after each phase of construction to discuss what worked and what did not. The success of the internal bracing caused the general contractor to create a lessons learned program so that the firm would be capable of using similar methods on future projects.

Lessons Learned

The methodology, design, and tactics used to perform the internal bracing for the structure. The plans, calculations, means, and methods would all be useful on future projects requiring internal bracing.

Case Study Project I

Location: Northeast
Type: Renovation
Class: New transportation facility
Project Delivery Method: Construction management/Design-build
Funding Source: Public
Designation: Award-winning project

Entities Interviewed
Owner
Construction manager (2)

Description of the Project
According to the project website this was a megaproject which rerouted the (roadway), the chief controlled-access highway through the heart of a large city in the Northeast, into a 3.5 mile (5.6km) tunnel under the city. The project also included the construction of a substantial tunnel. Initially, the project plan included a rail connection between the city's two major train terminals.

This project is the most expensive single highway project in the U.S. Although the project was estimated at $2.8 billion in 1985, over $14.6 billion had been spent in federal and state tax dollars as of 2006. The project has incurred criminal arrests, escalating costs, death, leaks, poor execution, and the use of substandard materials. The final facility opened in 2006.

Innovations on the Project
While there were many minor innovations, the major innovation on this project was the topic of most discussion. One interviewee felt that the tunneling of this magnitude was an innovation of the tunneling process. Through the use of ground freezing the surrounding soil was held in place during tunneling. Before ground freezing, the tunnel wall was specified to be held back by wood, nail boards, and face plates. Unfortunately the soil material that the contractor was going to be drilling through was an organic, soupy substance that did not hold up well. Instead, as part of a value engineering idea, the contractor suggested ground freezing. The material was drilled out in frozen chunks and disposed of. This process had been used on a very small scale but had never been used in such a large scale.

Enablers for Innovation
The following were identified as enablers for innovation on the project:

- Upper management support
- Innovation as part of the organizational strategy
- Cross discipline and encouraged communication
- Moderate support for R&D, significant support for value engineering
- Integration of the project team
- Owner allocation of resources for innovation

Barriers to Innovation
The following were identified as barriers to innovation:

- Unilateral communication
- Lack of innovation meetings
- Ineffective lessons learned
- Lack of time to explore new ideas
- Innovation not part of the innovation budget

Outcomes of Innovation
The following were identified as impacts to the project as a direct result of the innovation (besides being able to complete the project):

- Profitability
- Schedule performance
- Productivity
- Safety improvement
- Overall Owner satisfaction

Diffusion of Innovation
Because this project was high profile, there were many articles written on the project, means and methods of construction, and lessons learned. A formal lessons-learned/knowledge management program was not used to capture information about the ground freezing innovation.

Lessons Learned
No lessons learned were captured and identified in the case study interviews.

Case Study Project J

Location: Southwest
Type: Cathedral
Class: New facility
Project Delivery Method:
Funding Source: Private
Designation: Award-winning project

Entities Interviewed
Designer

Description of the Project
The challenge in designing and building a new Cathedral Church was to make certain that it reflected the diversity of all people. Rather than duplicate traditional designs of the Middle Ages in Europe, the Cathedral is a new and vibrant expression of the 21st century Catholic peoples of the city. The site is located between the Civic Center and the Cultural Center of the city. To the architect, the logic of these two competing interests suggested, first of all, a series of "buffering, intermediating spaces" -- plazas, staircases, colonnades, and an unorthodox entry. Worshippers enter on the south side, rather than the center, of the Cathedral through a monumental set of bronze doors cast by sculptor Robert Graham. The doors are crowned by a completely contemporary statue of Our Lady of the Angels. A 50-foot tall concrete cross "lantern" adorns the front of the Cathedral. At night its glass- protected alabaster windows are illuminated and can be seen at a far distance. The Cathedral rests on 198 base isolators so that it will float up to 27 inches during a magnitude 8 point earthquake. The design is so geometrically complex that none of the concrete forms could vary by more than 1/16th of an inch. The Cathedral is built with architectural concrete in a color reminiscent of the sun-baked adobe walls of the Southwestern Missions and is designed to last 500 years.

Innovations on the Project
The innovations identified by the interviewees on the project include:

- Unique cathedral design
- Base isolation for seismic performance

While these are unique aspects of the facility, they would not be considered as innovations based on the definition of innovation used in the research study. Base isolation has been used on previous projects and is becoming more popular in seismic zones for improving seismic performance.

Enablers for Innovation
No enablers of innovation were identified.

Barriers to Innovation
No barriers to innovation were identified.

Outcomes of Innovation
No outcomes of innovation were identified besides creating a unique structure that is designed to last 500 years.

Diffusion of Innovation
No diffusion of the identified innovations took place.

Lessons Learned
There was not a lessons-learned process utilized on the project.