

An Evaluation Framework for the Integrated Design Process of Sustainable High-Performance Buildings

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ABSTRACT

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Integration of disciplines and project participants is widely prescribed as a remedy to improve effectiveness and efficiency of construction projects. In the context of Sustainable High-Performance (SHP) projects, the Integrated Design (ID) process encourages implementation of systems-thinking and early intense collaboration of project stakeholders during the design phase. The desired outcome in this context would be buildings which not only have superior energy and sustainability performance over their life-cycle but also are cost effective.

This study attempts to: 1) identify the evaluation factors/items that could be used to measure the team performance in the ID process of SHP projects; 2) develop an evaluation framework for the ID process based on a systematic evaluation model; 3) validate the proposed evaluation framework; and 4) test the hypotheses that:

- a. 'More integrated design teams are able to achieve more successful SHP project outcomes'.

- b. 'More integrated design teams are able to gain more total LEED credits for their SHP designs'.
- c. 'More integrated design teams are able to gain more LEED credits in the Energy & Atmosphere category'.

To achieve the research objectives, a mixed-method (qualitative-quantitative) research methodology was applied. First, qualitative research (case-study and interview) and literature review were used to identify the critical factors in ID process and create a pool of the items that could be used to assess the performance of integrated design teams. These evaluation items were generated based on the Context, Input, Process, and Product (CIPP) evaluation model. In the next phase, the evaluation items were tested for content validity through expert review. The outcome was the development of the evaluation framework for the ID process of SHP projects. In the next phase of research, the proposed evaluation framework was validated through statistical analysis of a cross-sectional questionnaire survey of projects certified under the Leadership in Energy and Environmental Design (LEED) rating system. Internal consistency and multiple regression analysis were applied for assessing the reliability and validity of the proposed framework.

An Integrated Design Process Evaluation Framework was constructed with four components: a) an evaluation model (CIPP model), b) evaluation factors (27), c) evaluation items (65), and d) a measurement framework with three indices (Challenge Index (CI), Integration Assessment Index (IAI), and Performance Index (PI)). The results of statistical analysis showed the reliability and validity of the framework. The results also confirmed the research hypotheses and indicated that there is a significant positive effect of the integration of design teams on their achieved outcomes.

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1. INTRODUCTION

1.1. BACKGROUND AND SIGNIFICANCE

The demand for green buildings has increased in recent years, primarily because buildings and their construction have been proven to contribute significantly to some of the major environmental crises that the globe has been facing in recent decades. Indeed, every year buildings account for about 40 percent of extracted materials use, 40 percent of primary energy use, 70 percent of electricity consumption (EIA 2008), 30 percent of waste generation and 40 percent of CO₂ emissions (USGBC 2009). To address this problem, Sustainable High-Performance (SHP) buildings are designed and constructed to have superior energy and environmental performance. These buildings are rated against a set of strict performance requirements, prescribed by green building rating systems such as LEED (US), DGNB (Germany), BREEAM (UK), etc.

To design a successful SHP building, the Integrated Design (ID) process, which recognizes all systems associated with sustainability of a building, as well as their complex interactions over the complete life-cycle of the building, is applied. The ID process also tries to optimize the building's performance with respect to cost, energy consumption, and sustainability. The success of the Integrated Design teams in optimization of building's performance requires early intense collaboration of project stakeholders and implementation of extensive technical knowledge and systems-thinking during the design phase.

The survey of literature in the field shows that limited empirical research try to link the issue of 'integration' in construction to project outcomes (Baiden & Price, 2011). The literature review also reveals that there exists a lack of an effective framework for measuring and assessing collaboration (Xue, Shen, & Ren, 2010) and integration in construction projects in general, and in SHP projects in particular. Only one study attempts to pilot metrics for the ID evaluation (Korkmaz, 2007) while a few examine, empirically or qualitatively, the critical characteristics in design and delivery of green buildings (Korkmaz, 2007; Korkmaz, Swarup, & Riley, 2013; Li, Chen, Chew, Teo, & Ding, 2011). Therefore, the present doctoral dissertation has a threefold significance: firstly, it provides a systematic evaluation framework for the Integrated Design process of SHP projects. This framework could be used by owners and architects of SHP projects for evaluative and diagnosis purposes. Secondly, the proposed framework is validated through a quantitative study, and thirdly, the results of this research provide empirical support for anecdotal data suggesting that increasing integration in the design process can improve the achievement of outcomes.

1.2. RESEARCH OBJECTIVES

The following objectives are of interest in this research:

1. To identify the evaluation factors/items that could be used to measure the team performance in Integrated Design process of SHP projects;
2. To develop an evaluation framework for the ID process based on a systematic evaluation model;
3. To validate the proposed evaluation framework; and
4. To test the hypotheses that:

- a. 'More integrated design teams are able to achieve more successful SHP project outcomes'.
- b. 'More integrated design teams are able to gain more total LEED credits for their SHP designs'.
- c. 'More integrated design teams are able to gain more LEED credits in the Energy & Atmosphere category'.

1.3. RESEARCH METHODS

Mixed-method (qualitative-quantitative) research was applied to achieve the research objectives. Figure 1-1 illustrates various stages of this research as well as the methods that were applied.

First, a comprehensive review of literature in the field was conducted with the goal of providing an understanding of various aspects of the Integrated Design process and identifying its critical factors. Then, a qualitative research was applied aiming at developing a systematic evaluation framework for the ID process. The qualitative phase of research involved conducting a case-study research and in-depth interviews with industry professionals which resulted in an initial list of the evaluation items. This list functioned as a component of the evaluation framework. Expert review was then used to test the list for content validity. At the end of this phase, an evaluation framework for the ID process was proposed which consisted of the following four major elements:

- a. Evaluation model;
- b. Evaluation factors/sub-factors (27);
- c. Evaluation items (65); and
- d. A measurement format

This evaluation framework was generated based on the Context, Input, Process, and Product (CIPP) evaluation model (Stufflebeam, 1983; Stufflebeam, 2003), which is a widely used model of evaluation in educational and business contexts.

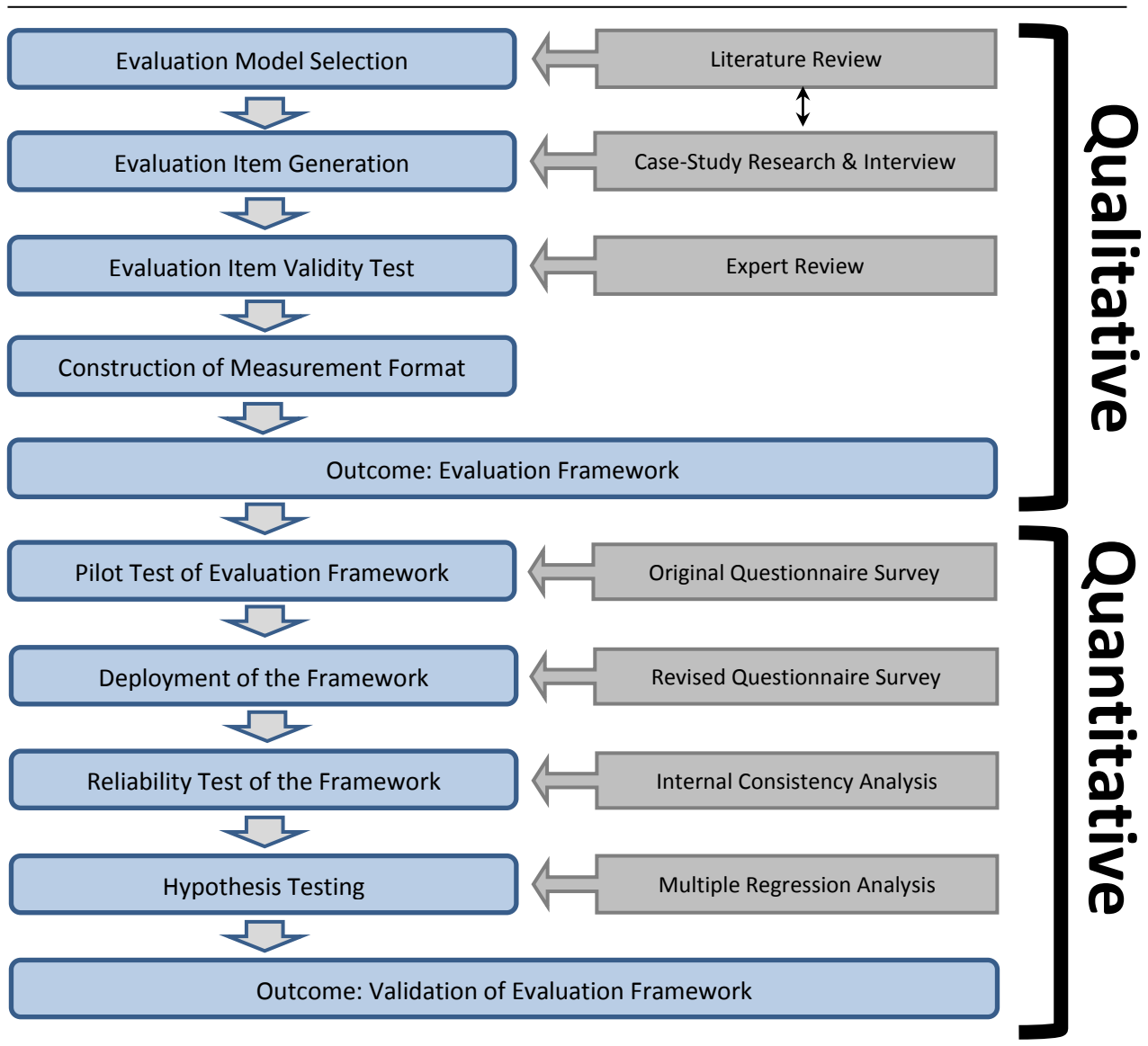


Figure 1-1. Research Methodology

The next phase of research, the quantitative phase, was conducted to validate the proposed evaluation framework. In this phase, the framework was incorporated into a questionnaire survey which was pilot tested, revised, and distributed among project participants involved in delivery of LEED-rated buildings. The collected responses were analyzed for quantitative reliability and validity. More specifically, the framework's reliability was examined through the internal consistency method, and measures such as Cronbach's Alpha, Inter-Item correlation, and Item-Rest correlation. In addition, multiple regression analysis was used to validate the framework for construct and internal validity and to test the research hypotheses. Finally, the results of the analysis were interpreted and final conclusions were developed.

1.4. RESEARCH SCOPE

The scope of this study is limited by three major issues. Firstly, this research focuses only on SHP projects. As a result, its results and conclusions should be interpreted only within the context of this type of construction projects. Secondly, the Integrated Design process, rather than Integrated Project Delivery (IPD), is the scope of interest in this research and, therefore, the research focus is primarily on team dynamics in the design process and the parameters that affect the performance of design teams. Thirdly, the micro-level factors/activities concerning the internal working processes of the SHP project participants were not considered in this research because they could dramatically expand the research scope and their presence could make the evaluation function complex and impractical.

1.5. DISSERTATION STRUCTURE

The present study consists of 6 chapters. Figure 1-2 illustrates the structure of the dissertation.

The first chapter (Introduction) provides background on the research and a statement of the problem. It also introduces the research objectives, methods, scope, and structure.

The second chapter focuses on literature review and surveys three major realms of SHP buildings, the notion of integration in various contexts, and evaluation. The literature review results are then summarized in the 'Synthesis of Literature' section.

The third chapter details the research methodology and methods that were applied in the present research. This chapter provides an overview of various research philosophies, approaches, and methods and explains the rationale for selecting the specific methodology and methods of the current research. It then describes the applied research methods in detail.

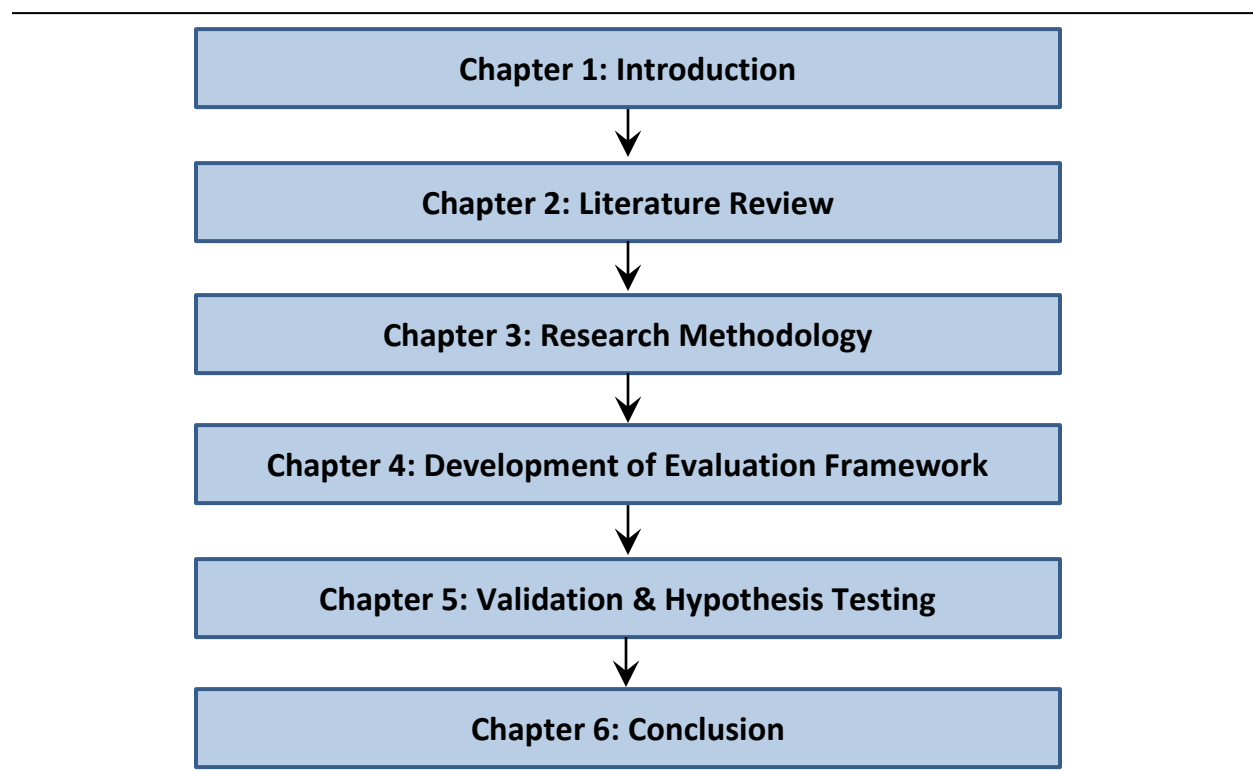


Figure 1-2. Dissertation Structure

The fourth chapter covers the procedure of developing the evaluation framework for the Integrated Design process. The qualitative research used to develop the framework and the structure of the proposed framework are described in this chapter.

The fifth chapter focuses on the validation of the evaluation framework and testing the research hypotheses. The process of quantitative research that was applied is covered in this chapter and its results are interpreted.

Finally, the sixth chapter (Conclusion) provides a summary of the research and its findings, describes some of the limitations of the research, and makes recommendations for future research in this area.

2. LITERATURE REVIEW

A survey of existing literature is critical to understanding various aspects of the Integrated Design (ID) process of Sustainable High-Performance (SHP) buildings and locating the gaps in the existing knowledge. The present chapter starts with a background on SHP buildings, their definitions, and some of the challenges and opportunities in their design and delivery. Then Integrated Design (ID), as an approach to designing SHP buildings is explored through the literature. Since the concept of integration is a fundamental principle of Integrated Design, its definitions and applications are then examined across a variety of disciplines, including organizational development, management, and design and construction. The aim of this part of the literature review is to identify the critical factors associated with the concept, especially in the settings of SHP projects' design. This chapter then focuses on 'evaluation' and 'measurement' theories and reviews some of the major literature in these realms, concluding with a synthesis of the surveyed literature.

2.1. SUSTAINABLE HIGH-PERFORMANCE (SHP) BUILDINGS

Sustainable High-Performance Buildings are developed to have superior performance with respect to various environmental categories, such as energy use, water consumption, and resource consumption.

2.1.1. Background and Definitions

The concept of sustainable development was initiated and spread in the 1980s as a result of the burgeoning concerns over the extent of natural resource degradation and climate change. The concept basically mandates using natural resources for meeting humans' needs in such a way that the availability of the resources to coming generations is not compromised (WCED, 1987). Sustainability is measured through the triple-bottom approach, which simultaneously considers social, environmental, and economic impacts of human activities (Elkington, 1998).

The construction industry is among the major consumers of energy and natural resources. It also has a significant role in producing wastes and emissions that jeopardize the health, life, and survival of humans and animal species. Statistics show that buildings are consuming about 40 percent of extracted materials, 40 percent of primary energy and more than 70 percent of electricity in the United States (EIA, 2008). They also generate 30 percent of the waste produced in the US (USGBC, 2009). Figure 2-1 shows some of the environmental damages that buildings cause in this country.

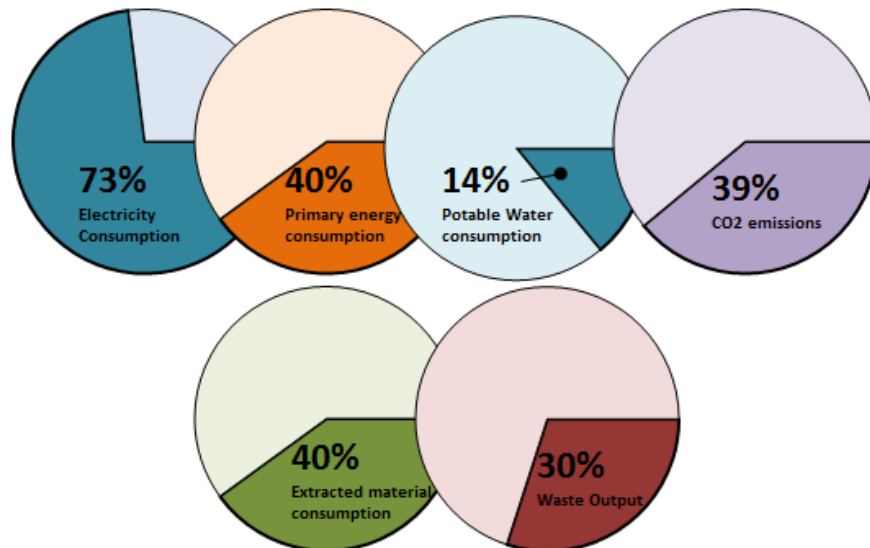


Figure 2-1. US Buildings' Share in Causing Environmental Damages
(Based on the data provided by US Department of Energy and USGBC)

Sustainable construction and green buildings have emerged as the response of researchers and practitioners in the construction industry, to lessen the resource consumption and environmental impacts associated with buildings' life cycles and to improve the part of human health that is impacted by construction and operation of buildings (Kibert, 2008). The outcomes of sustainable construction are labeled with various terms such as 'green buildings', 'sustainable buildings', 'high-performance buildings', 'net-zero energy buildings', etc. While the terms are often used interchangeably, their focus is indeed different.

'Sustainable building' is a broad term with various definitions. It can be defined as a building that is designed using a four-R approach (Lechner, 2009): Reduce (waste generation, energy use, and GHG emissions, etc.), Reuse (materials and buildings), Recycle (materials and building components), and Regenerate (i.e. attempt to restore the environment to its conditions before being degraded by humans). In this definition, sustainable buildings not only try to lower their negative environmental impacts (through reduce, reuse, and recycle) but also seek to heal their relationship with the environment in a positive way (through regeneration).

The term 'Green building' focuses mostly on environmental impact reduction. It is defined by the US Environmental Protection Agency (EPA) as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction" (EPA, 2010). Green buildings, according to the EPA, are designed to improve resource (energy, water, etc.) efficiency, protect human health and productivity, and reduce waste and environmental degradation. Kwok and Grondzik (2007) believe that sustainable buildings achieve broader objectives than green buildings by taking into account the triple-bottom approach and considering the relationships between ecology, economy, and social well-

being. The two terms, however, are still used interchangeably in much of the construction industry to refer to the same concept.

'High-Performance building', another term, is defined by the Energy Policy Act (2005) as "a building that integrates and optimizes all major high-performance building attributes, including energy efficiency, durability, life-cycle performance, and occupant productivity." The superior performance of high-performance buildings, compared to conventional buildings, is believed to result in more tangible economic values in the long-term. The design of high-performance buildings therefore focuses on a range of issues from energy, water and resource efficiency to indoor environmental quality improvement to maximizing economic value (Kibert, 2008; Korkmaz, 2007; USGBC, 2009).

Energy-efficient buildings are a type of High-Performance building with superior energy performance and 'Net-Zero Energy' buildings are energy-efficient buildings which produce as much energy as they consume, on a net annual basis, from on-site renewable sources (DOE, 2009). As suggested by this definition, the design focus of these buildings is to provide the building with energy independency on a net annual basis.

Figure 2-2 tries to distinguish the various terms within the realm of sustainable construction based on their above-mentioned definitions.

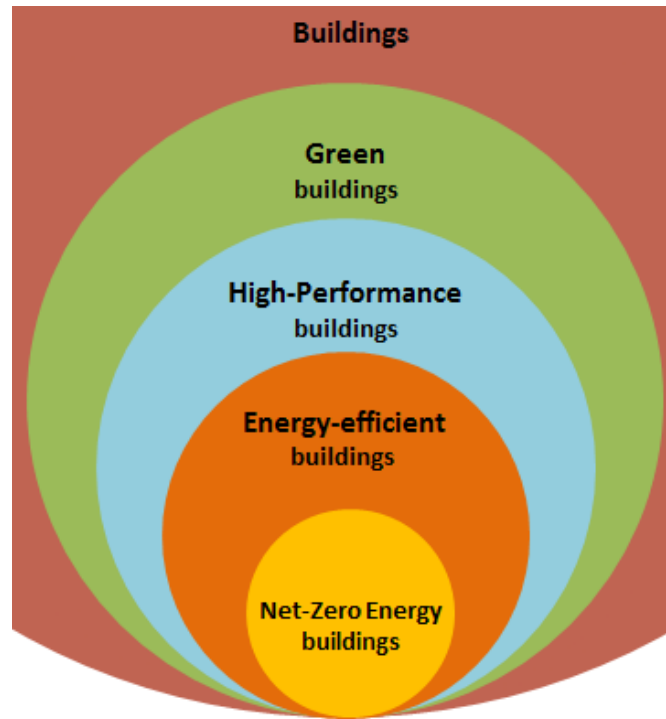


Figure 2-2. Various Types of Sustainable Buildings

2.1.2. Benefits and Barriers

The literature highlights a variety of environmental and economic benefits associated with Sustainable High-Performance (SHP) buildings. These buildings often make better use of natural conditions, such as daylight and wind, and apply improved design and construction techniques, such as insulation and thermal mass, to reduce their energy demands and meet the requirements of green building rating systems. They also contain materials with low rates of harmful compound emissions, and therefore provide healthier interior environments to live and work in. Considering the fact that Americans on average spend more than 90 percent of their time inside buildings (EPA, 2009), living and working in healthier buildings would lead to higher rates of productivity. This in turn can bring more economic values to the owners of these buildings. SHP buildings also enjoy lower operational and maintenance costs, due to their energy-efficient strategies, which can offset higher initial construction costs.

Environmental benefits of SHP buildings are often in the form of reduced negative impact to the environment when compared to conventional buildings, rather than real benefits. Indeed, there is a long road ahead of us in achieving buildings that are not harmful at all to the surrounding environments. Until then, the target of most SHP buildings is to mitigate to near-zero their environmental damages. For instance, Net-Zero Energy buildings, which are currently considered the desired SHP buildings, produce as much energy as they consume over the course of a year and, thus, are considered carbon-neutral. However, these buildings are still not able to heal the damaged ecosystems within the surrounding environments. Healing and restoring the environment is the next target of sustainable construction, and is usually referred to as regeneration (Kibert, 2008).

There are also barriers and obstacles to widespread adoption of SHP buildings. First of all, the benefits of these buildings have yet to be fully perceived by most of the average residential owners and, as a result, more attempts to raise public awareness are needed. Another obstacle is current building codes, which only define the minimum performance requirements without encouraging building owners to go beyond the minimums. Moreover, SHP buildings are not perceived as competitive based on initial costs, which are usually more important to owners. Many professionals in the construction industry believe that building greenly adds 10 percent or more to the cost of buildings (Yudelso, 2008).

Hoffman and Henn (2008) is one of the most comprehensive studies in identifying social and psychological barriers to green buildings. They categorize these barriers at three different levels of individual, organizational, and institutional. Some of the major barriers at the individual level include (Hoffmann & Henn, 2008): owners' mindset and resistance to making the right long-term decisions on energy-efficiency, making unfair decisions toward sustainable built environments

(such as construction in the suburbs), tendency to perceive conditions as better than what reality suggests, making judgments based on connecting unrelated phenomena (such as connection of less water consumption with less cleaning), lack of environmental literacy, etc. Organizational-level social and psychological barriers to green buildings, according to Hoffmann and Henn (2008), include: resistance to the free flow of information in design and construction project teams, conflicting cultures, resistance to change, etc. Institutional-level barriers to green buildings include issues such as regulatory limitations, institutional resistance to change, etc. (Hoffmann & Henn, 2008). To overcome these barriers, they suggest a variety of measures ranging from adoption of new practices and educational improvements to tax reforms.

2.1.3. Systems to Assess and Rate

A major issue in the field of green construction is to identify the SHP buildings and assess their sustainability performance. To do this, a variety of green building rating systems have been developed to assess and rate the performance of buildings in achieving sustainable targets. Without these systems, the achievement of green targets cannot be realized by all project stakeholders. These systems usually have a set of requirements in various categories that address sustainability issues, such as water efficiency, energy efficiency, indoor environmental quality, etc., over the life-cycle of a project. Some of these rating systems include LEED, Green Globes, Living Building Challenge, and BREEAM.

In the US, Leadership in Energy and Environmental Design (LEED) is the main system to assess and rate SHP buildings. LEED rating system assesses the performance of a building in six performance categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation in design (USGBC, 2009). The system is used to assess buildings of various types such as commercial, school, healthcare, commercial interior, etc. Buildings are awarded points for meeting the requirements

of performance categories, and eventually receive a total score that reflects their sustainability performance in relation to other buildings. Then, they are rated based on their achieved score. Based on LEED-NC v3, the version of LEED for New Construction projects, achieving 40-49 credits out of 110 possible credits would result in “Certified” level of certification by the US Green Building Council (USGBC). Achieving 50-59, 60-79, and 80+ credits would lead to “Silver”, “Gold”, and “Platinum” levels of certification, respectively. While LEED has had a major role in encouraging sustainable buildings, some criticize that chasing points, rather than actual sustainability objectives, has become the goal of project teams in pursuing LEED (Hoffmann & Henn, 2008).

‘Living Building Challenge’, another green building assessment and rating system, is in the frontier of the move towards buildings with no environmental impacts. It is an advanced rating system which measures the sustainability performance of buildings in seven categories, called “petals”, of site, water, energy, health, materials, equity, and beauty (ILBI, 2010). To achieve “Living” status, buildings must meet all the performance requirements in the seven petals and do so through actual data, rather than modeled data (ILBI, 2010).

2.2. INTEGRATED DESIGN

‘Integrated Design’ (ID) is the approach that is applied in designing SHP projects. Since integration is the fundamental principle of Integrated Design, the concept in various fields is first examined, and its application in the context of SHP projects is then explored.

2.2.1. Integration in Organizational Theory and Product Development

Integration is traditionally interpreted as coordination and collaboration of interdependent subsystems in order to achieve the characteristics of a unified whole in a system. The more

differentiated a system, the higher the needed level of integration (Glouberman & Mintzberg, 2001).

Organizations consist of interdependent components (people, departments, etc.) that work together towards specific organizational outcomes or products, and the concept of integration is believed to be essential in understanding them (Barki & Pinsonneault, 2005). In this context, some definitions of integration view it as kind of high-level collaboration among the subsystems of an organization. Lawrence & Lorsch (1986), for example, define integration as “the quality of the state of collaboration which exists among departments that are required to achieve unity of effort because of environmental demands” (Lawrence & Lorsch, 1986). Some other definitions, however, focus on characteristics of the organizational components and the product of their collaboration in order to define integration. An example of these definitions is Barki & Pinsonneault (2005) which define integration as “the extent to which distinct and interdependent organizational components constitute a unified whole”. This definition emphasizes the “distinctiveness” and “interdependency” of the subsystems in organizational integration and the resultant unified system. Less explicit in this definition is the collaboration of the subsystems (or components) in the process of integration. Both categories of definitions, however, agree that achieving unity is a key element of integration.

In the context of product development, integration is primarily viewed as communication and collaboration among units and coordination of information or activities among them, in order to develop a product. Kahn (1996) made a comprehensive review of previous definitions of integration in this context and categorized them into two major groups: one group that views integration as communication/interaction (in the form of formal meetings, etc.) and another group that defines the concept as collaboration (shared goals, etc.). He then defined integration

as “a multidimensional process that comprises two distinct processes of interaction and collaboration” (Kahn, 1996).

The empirical research in these contexts generally suggests a positive relationship between integration and project performance (Lawrence & Lorsch, 1986; Kahn, 1996; Koufteros, Rawski, & Rupak, 2010), even though mixed and contradictory results (Barki & Pinsonneault, 2005) are also generated due to various operational definitions offered for the concept of integration as well as project performance.

2.2.2. Integration in the Context of Construction Industry

In the construction industry, the term integration is often interchangeably used with collaboration (NASFA, COAA, APPA, AGC, AIA, 2010) and refers to an environment in which project stakeholders work closely together as a team towards project objectives through sharing of information, joint operations (such as decision-making, etc.), and alignment of their cultures (Baiden & Price, 2011; Baiden, Price, & Dainty, 2006; Dulaimi, Ling, Ofori, & De Silva, 2002; Mitropoulos & Tatum, 2000; Rahman, Kumaraswamy, & Ling, 2007). Nam and Tatum (1992) use integration as an antonym to disintegration which, according to them, is the outcome of “incongruent goals and consequent divergent behaviors” in construction projects. They also state that there is a close relationship between integration and cooperative project environments. Similar to this application, Baiden and Price (2011) define integration as “where different disciplines or organizations with different goals, needs and cultures merge into a single cohesive and mutually supporting unit with collaborative alignment of processes and cultures”. According to them, integration requires a cooperative environment in order to overcome adversarial relationships. In their study, they develop a Team Integration Matrix, which evaluates integration based on the six dimensions of ‘single team focus’, ‘seamless operation

without organizational boundaries', 'free sharing of information', 'single co-located team', 'equitable team relationships' and 'no-blame culture' (Baiden & Price, 2011).

The need for integration in the construction industry primarily results from the fact that a fragmented approach to construction procurement has led to a lack of efficiency and effectiveness in delivery of projects with respect to time, cost, etc. (Love et al. 1998, Baiden et al. 2006). In other words, high wastes, increased project cost and time, and adversarial relationships in the industry can be traced back to separated traditional project organizations (CMAA, 2010). Mitropoulos and Tatum (2000) believe that this fragmentation is a result of two major factors: the complexity of construction projects and the high degrees of specialization involved in design and construction of projects. Construction industry experts agree that to overcome problems arising from projects' complexity, diverse specializations in the industry, and the subsequent fragmentation, there exists a need to move towards more collaborative and integrated approaches in order to decrease the uncertainties that surrounds construction projects and to deliver more predictable results to clients (Egan, 1998; Egan, 2002; Love, Gunasekaran, & Li, 1998; Mitropoulos & Tatum, 2000; Fairclough, 2002; CMAA, 2010).

Mitropoulos and Tatum (2000) believe that integration is critical in building design for two reasons: to avoid problems that might arise in construction and post-construction phases and to select design alternatives that optimize overall project performance. Integration in design, as they suggest, addresses both design and construction phases of a project and implies the involvement of contractors and suppliers in information sharing and decision-makings of a project (Mitropoulos & Tatum, 2000). Similarly, other studies in the context of the construction industry often use integration in design with the same implication (Nam & Tatum, 1992; Dulaimi, Ling, Ofori, & De Silva, 2002).

As a project's uncertainty, complexity, and speed increases, the integration between project parties is more needed (Mitropoulos & Tatum, 2000), because under these conditions decisions should be based on higher levels of reliable information at critical times in the planning and design process. In complex construction projects, there would be a need to create an environment of free exchange of information from the early stages of project development. In other words, owners, contractors, various designers, subcontractors, suppliers, consultants, and users, as the major stakeholders in construction projects, must participate in making key decisions at the right time during the project's development as an integrated project team (CII, 1998; Rahman & Kumaraswamy, 2004; Ballard, 2006). The goal of this integrated project team would be to investigate market values, define the project, set target values, allocate risks, and design and deliver the project (Ballard, 2006). Some beneficial consequences of integration in project delivery include: better scope definition, more informed decisions, better identification of needs, constraints and priorities, increased cost-effectiveness, increased competitiveness, and lower levels of change, rework and delays (Mitropoulos & Tatum, 2000).

Less explicit in the discussions around integration is 'integration thinking', or 'systems-thinking', which refers to considering the relationships among constituent subsystems of a system in order to create an optimized performance. In this type of thinking, the decision-makers of a project realize that a decision about one subsystem would impact the performance of other subsystems. Therefore, any decision-making on that subsystem must be made after consideration of all impacts on other subsystems. This, in turn, requires the involvement of all disciplines, which are representative of subsystems, in the decision-making process. Systems-thinking is a key element in an integrative design and construction environment as it causes the diverse disciplines in a project team to make decisions with the goal of optimizing the performance of the construction project as a whole, instead of mere optimization of its subsystems (Mitropoulos & Tatum, 2000).

Synthesizing previous definitions and elements of integration, integration in this research is defined as 'collaboration among project stakeholders with the goal of creating a systems-thinking environment in order to deliver optimized value to the client'. Creating such an environment requires free exchange of information and joint operation (shared-goal setting, joint decision-making, etc.).

The degree of achieved integration in delivery of a construction project is subject to applied 'Contractual', 'Organizational', and 'Technological' mechanisms (Mitropoulos & Tatum, 2000). Cross-functional teams and informal relationships are some examples of organizational mechanisms. Relational contracting and Building Information Modeling (BIM) can act as contractual and technological mechanisms for achieving integration, respectively. All these mechanisms are designed to bring all project parties to the table and facilitate their full integration in a project.

CII (2012) is an example of the studies that explores the relationships between the levels of challenges in capital construction projects, integration and project outcomes. This study uses a combination of previous literature and a case-study research on 20 capital construction projects to qualitatively test the hypothesis that: "Complex, uncertain, and quick projects perform better when designed and managed in accordance with alignment of interests, organizational integration, and management by means methods." (CII, 2012). To test this hypothesis, the study examines the relationships between the Challenges Index (CI), Performance Index (PI) and Organizational Integration (OI). Challenges Index (CI), in the context of this study, consists of uncertainty, complexity and speed of project. Performance Index (PI) measures project success (cost, time, etc.) as well as quality of relationships. As shown in Figure 2-3, CII (2012) shows that organizational integration should be increased in order to go from the lower half of the

quadrant diagram, which represents low-performing projects, to the half above it, which represents high-performing projects. Also, it shows that organizational integration increases by going from less-challenging low-performing projects to highly challenging projects, although that is not the case with going from less-challenging high-performing projects (quadrant 4) to highly-challenging high-performing projects (quadrant 3). There are, however, some limitations associated with this research. Firstly, it does not test the hypothesis through a quantitative research and, therefore, the results are not generalizable to all capital projects or all types of construction projects. The second limitation has to do with the results. Indeed, further research needs to be conducted to explain why, in quadrant three of Figure 2-3 which represents projects which are both high-performing and highly-challenging, the level of organizational integration is not at the highest average level among case-studies. Also, future research needs to dissect why highest level of organizational integration takes place in quadrant 4 which represents projects which are high-performing but with low levels of challenges. CII faces others limitations too which will be covered in more detail in Section 5.4; Chapter 5.

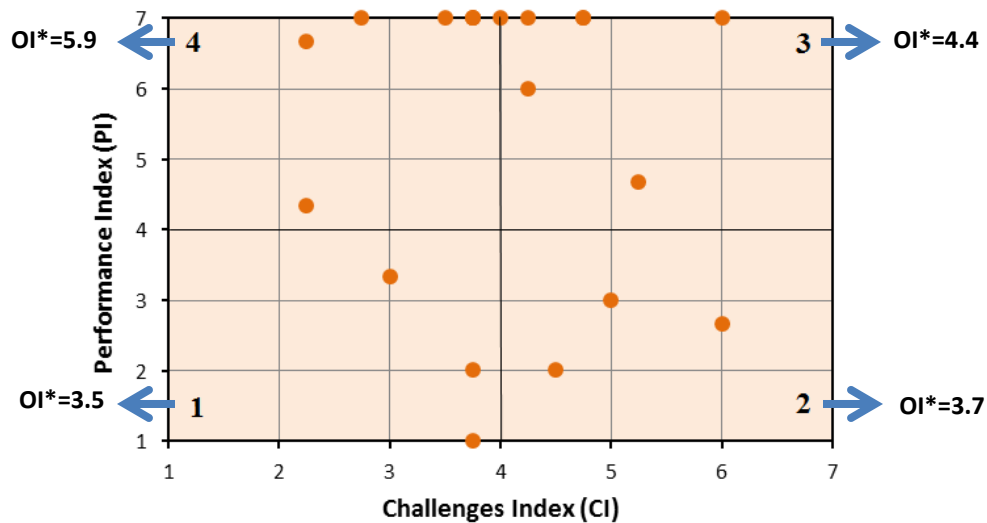


Figure 2-3. Relationship Between PI, CI and OI, According to CII (2012)
(OI=Organizational Integration; The value represents the average across case-studies)

2.2.2.1. Integration and Construction Project Delivery Systems

The organizational and contractual mechanisms for achieving integration are usually embedded in the framework of project delivery systems. Various project delivery systems allocate roles and responsibilities differently and implement different sequencing of project phases and activities. This results in different degrees of integrated project environments. In general, project delivery systems with more integrated project sequencing tend to benefit from more integrated project team environments. It might be interesting and useful to briefly review the history of project delivery systems in order to better understand how integration of professionals in the construction industry has changed over time.

Ancient construction projects were constructed through a highly integrated approach in which a single individual was responsible for design and supervising construction of the project. The Code of Hamurabi, written by Hamurabi, the ruler of Babylon, makes reference to the singular responsibility of builders in design and construction of buildings, so that the owners' interests are protected (Beard, Loulakis, & Wundram, 2001). This integrated approach to project delivery, which is known as the 'master-builder' approach, was dominant from ancient times through the medieval ages to the early nineteenth century, even though it was challenged for the first time in 15th century (Cushman & Loulakis, 2001). In this approach the master-builder designed a building, provided materials for construction, supervised laborers, and delivered it to the client. In doing all of this, he functioned as a single entity.

With the advancement of technology in the nineteenth century and the emergence of new building types, such as factories, the need for high levels of design expertise emerged too. As a result, separate design and construction professional organizations started to emerge in order to advance their knowledge, distinguish themselves, improve their prestige (Cushman & Loulakis, 2001), and protect their reputation and integrity (Beard, Loulakis, & Wundram, 2001).

In the twentieth century, the US government further separated design and construction by establishing laws that tried to protect the public interests by requiring the selection of contractors for public projects based on the lowest responsible bid and selection of designers based on the quality of their designs (Beard, Loulakis, & Wundram, 2001; Cushman & Loulakis, 2001). This resulted in the advent of Design-Bid-Build (DBB) project delivery. DBB was later proven inefficient because of the high levels of separation between project parties, which led to long delays and a large number of claims and disputes associated with that (Beard, Loulakis, & Wundram, 2001). Moreover, more complex projects needed more coordination which was not achievable through DBB (Beard, Loulakis, & Wundram, 2001; Cushman & Loulakis, 2001). Construction Management (CM) and Design-Build (DB) project delivery systems were developed in response to these problems. CM applied contractors' advice on design early in the project development phase and assured owners that the designs provided by architects and other designers were practical and cost-effective. In DB, the contractor takes all of the risk to design and construction of the project. This can potentially reduce the cost and duration of projects and minimize the conflicts between project parties.

A recent approach to project delivery is Integrated Project Delivery (IPD), introduced to deliver value to owners by increasing collaboration and integration among parties. The IPD projects usually integrate four areas in construction practice (CMAA, 2010): agreements (multi-party contracts between key team members), leadership, information (BIM, etc.), and processes (adoption of lean theory). In contrast to some project delivery systems, such as Design-Bid-Build (DBB), which offer low levels of integration, IPD provides the opportunity for higher levels of integration among project participants. This approach to project delivery is still new to the industry and has not yet been widely applied in construction.

2.2.3. Integration and Integrated Design of SHP Buildings

The concept of integration has also been applied in the context of SHP building design. To help better understand how SHP buildings are designed using the Integrated Design approach, it might be more helpful to first explore how conventional non-SHP buildings are designed.

2.2.3.1. Design Process of Conventional Buildings

To develop conventional buildings, the client usually refers to the architect with the feasibility study. The architect prepares a schematic design based on the program requirements. Following the client's approval of the schematic design, the architect refines the design and sends it out to other designers and engineers to solve technical issues related to mechanical, electrical, structural, and other systems. The work of engineers on design is usually accomplished in their own offices with little communication with the architect or representatives from other engineering disciplines. After solving the issues related to their own discipline, they send their work to the architect who then coordinates all drawings based on the works received from all engineers. At the end of this phase, Design Development, all engineering and construction issues are finalized and coordinated with everyone on the team.

The next phase is Construction Documentation which is done based on the approved outcome of the design development phase. At this phase, detailed drawings sufficient for construction of the project are prepared and their compliance with codes is finalized. These drawings and other contract documents are used in the next phase of the project which is bidding, negotiation, and contractor selection. The contractor is usually selected based on a combination of proposed cost and other criteria such as experience, qualifications, etc. The selected contractor then constructs the project based on the contract documents.

A major challenge of this process, which results in inefficiency, is low levels of communication between project participants in designing the interdependent systems of a building; i.e. between architects and engineers, between contractors and architect/engineers, and so forth. A classic example of the interdependency of systems is the effect of wall color on lighting and the sizing of mechanical systems (7group & Reed, 2009; Yudelso, 2008). The change of a wall's paint color changes its reflectivity, which in turn impacts the needed lighting levels in a space. The subsequent change of the size and type of electrical lights results in different levels of heat generated as a by-product of the lights' performance. This, in turn, can impact the sizing of mechanical systems. This example clearly shows the need for communication among the architect who picks the wall color, the electrical engineer who designs the electrical and lighting systems, and the mechanical engineer who designs the HVAC systems. Due to low levels of communication in the conventional design process, decisions made during the design process are not usually optimal with regard to performance of the systems and with respect to the life-cycle costs of the project. More specifically as related to mechanical systems, this can lead to inappropriate design features, such as limited use of solar gain during heating season (which would result in higher heating loads in winter), higher cooling loads in summer (because of excessive glazing area), exposure of occupants to visual and thermal discomfort (due to spatial organization facing west), etc. (IEA, 2003). As a result, poor performance and high operational costs are inherent to most examples of buildings designed through conventional design processes.

Lack of communication in the conventional design process also creates time delays in project delivery which, in turn, can lead to cost overruns. Moreover, adversarial relationships are a natural result of this process because project team members pursue their individual interests rather than shared agreed-upon project interests and goals.

2.2.3.2. Integrated Design Process

National Workshop on Integrated Design Process in 2001 is among the first to define the Integrated Design (Kibert, 2008). It defines integrated design as a 'collaborative process that focuses on the design, construction, operation and occupancy of a building over its complete life cycle'. The International Energy Agency (IEA, 2003) defines it as "a procedure considering and optimizing the building as an entire system including its technical equipment and surroundings and for the whole lifespan. This can be reached when all actors of the project cooperate across disciplines and agree on far-reaching decisions jointly from the beginning". US Department of Energy (DOE) defines the term as 'the process in which multiple disciplines and seemingly unrelated aspects of design are integrated in a manner that permits synergic benefits to be realized'. Kwok and Grondzik (2007) define integrated design as "a process that applies the skills and knowledge of different disciplines and interactions of different building systems to synergistically produce a better, more efficient and more responsible building..."

The extensive literature on Integrated Design (ID) process agree that the ID process recognizes the interdependency of building systems, the complexity of green building design, and the need for early collaboration of all disciplines in order to make optimum decision for the whole building (IEA, 2003; Yudelson, 2008; 7group & Reed, 2009; Kibert, 2008).

Buildings consist of complex interdependent systems which act like cogs in a gear. The design of a functioning gear requires the proper design of the cogs and consideration of the relationships between them. The same is true with buildings in that all constituent systems of a building, including structural, mechanical, electrical, etc., must function well not only individually but also in combination with each other.

This issue becomes more important in the design of Sustainable High-Performance (SHP) buildings. Higher levels of complexity and innovation are needed in the design of SHP buildings. Project team members often face design challenges with which they, individually, might possess low experience or expertise. They may need to bring in specialists, such as energy modelers, lighting designers, green design champions, etc., that are not typically included in conventional design teams. Moreover, SHP buildings need to meet the complex requirements of green building rating systems (such as LEED, Living Building Challenge, etc.) and need to compete with conventional non-SHP buildings with respect to cost. All of these highlight the fact that, to design an optimally-functioning SHP building, the team has to design all building systems as a unified whole, by considering the impacts of all systems on other systems' performance (Yudelson, 2008; 7group & Reed, 2009; Kibert, 2008). Achieving the integration of systems requires integration of the representatives of all design disciplines in a team to freely share their information and collectively design the building.

Therefore, integration, in the context of the Integrated Design (ID) process, implies using a collaborative team of architects, engineers, building occupants, contractors, etc. to collectively consider various aspects of sustainability (water efficiency, energy efficiency, site, indoor environmental quality, etc.) from the earliest stages of building design and to realize the synergies and tradeoffs between them over the life-cycle of a project. The outcome would be an optimized building that provides a healthy productive environment for the occupants, is sustainable to environment, and generates value to owner.

Researchers and practitioners in the industry usually have a similar approach to integrated design, even though their focus might be slightly different. Kowk and Grondzik (2007) highlight several steps toward integrated design. According to them, these steps include establishing commitment, team formation and setting of goals, information gathering, conceptual and

schematic design, testing, design development, construction, and assessment and verification. Yudelson (2008) lists the elements of integrated design as commitment to integrated design, setting goals and criteria for the team, commitment to zero cost increase, front-loading the design process with environmental charrettes, allocating time to feedback and revisions before committing to final design selection, and engagement of all team members in all decisions. Yudelson (2008) also reports the perspective of Bill Reed, an architect and writer, on integrated design. The main elements of integrated design, according to Reed, include inclusion of owners in decision making, team selection, alignment of expectation and purposes, goal-setting, identification of team champion, early optimization of the systems using an iterative process, commitment of design team to the entire process, commissioning and ongoing monitoring and maintenance (Yudelson, 2008).

While these and other studies have been successful in highlighting the major elements or factors in ID process of SHP projects, no study has thus far tried to provide a systematic method to evaluate how integrated an integrated design team is.

2.3. EVALUATION

Since a major objective of this dissertation is to provide a systematic framework for evaluating the ID process, the evaluation concept is explored in this section.

Evaluation is a part of our daily activities and conversations. When we talk about a soccer match, presidential candidates, a relationship with a friend, weather, or the quality of our lives, we constantly make evaluations. Evaluation, as a discipline, is defined as “the systematic process of delineating, obtaining, reporting, and applying descriptive and judgmental information about some object’s merit, worth, probity, feasibility, significance, and/or equity” (Stufflebeam &

Shinkfield, 2007). The evaluation theory is founded on two pillars; accountability and systematic social inquiry (Alkin & Christie, 2004). Accountability is the process of “being answerable or capable of being accounted for” and “is designed to improve the program or society” (Alkin & Christie, 2004). Systematic social inquiry, another pillar of evaluation, concerns the methods used to determine accountability (Alkin & Christie, 2004). In other words, based on this theory, evaluation information is collected in order to assess the merit, worth, and significance of a process, product, or project, and to improve the accountability of its stakeholders.

Evaluation, in practice, is conducted for four major purposes: improvement, accountability, dissemination, and enlightenment (Stufflebeam & Shinkfield, 2007) and needs a framework through which the evaluator is able to assess all aspects of a phenomenon. A famous evaluation framework that is widely used in educational, management, and business contexts, and that is applied in this research too, is the Context, Input, Process, Product (CIPP) framework. This framework, developed by Stufflebeam (1983), will be introduced in more detail in chapter 4.

Most often, evaluation is linked to measurement. When we want to evaluate the presidential candidates' prospects, we use public opinion polls, and when we make a judgment about weather, we refer to temperature, relative humidity, and other climate factors that can be measured to act as the basis of evaluation.

One of the major evaluation efforts in the field of construction management has been made by Kwak and Ibbs (2002). They developed an evaluation framework to determine and benchmark the maturity of project management in an organization. This model, which is called the 'project management process maturity model', introduces a quantified framework for measuring project management level in nine knowledge areas (integration management, scope management, time

management, cost management, quality management, human resource management, communication management, risk management, and procurement management). These nine areas are measured in five project processes of initiating, planning, executing, controlling, and closing, and provide a basis for assessing the maturity of project management.

Another major effort was the 'project definition rating index' developed by the Construction Industry Institute (CII). This model (CII, 2006) evaluates the maturity of a project with respect to scope definition, and provides quantitative criteria for linking it to project performance.

In all of these frameworks, the areas or factors for evaluation are first identified, then tangible definitions, or evaluation items, for evaluating them are generated under a systematic framework. Then, a measurement model is used to quantify the performance of a project with respect to the subject of evaluation. Likewise, for a systematic evaluation of the Integrated Design process of SHP projects, valid and reliable evaluation items need to be identified and organized into a quantifiable model. This framework then needs to be tested for validity.

2.4. SYNTHESIS OF LITERATURE

The review of literature revealed that Sustainable High-Performance buildings are the construction industry's response to existing environmental challenges. These buildings are designed through an approach called Integrated Design (ID). The notion of integration, as the fundamental principle of Integrated Design, is a broad concept and widely used in the context of the construction industry. The factors necessitating integration in construction projects include the complexity of construction projects, diverse specializations and disciplines involved in the industry, the existing inefficiency of project outcomes, and the need for optimization. Integration in construction literature is often used interchangeably with collaboration without a highlighted

reference to its other important component, systems-thinking. Therefore, the author of this manuscript suggests that integration could be more inclusively defined as “collaboration among project stakeholders with the goal of creating a systems-thinking environment in order to deliver optimized value to the client”. Free exchange of information, joint operation (shared-goal setting, joint decision-making, etc.), etc. are some critical factors in achieving such an environment.

While all discussions regarding integration in construction are applicable to the context of SHP buildings, the notion of integration in the design process of SHP projects has additional goals. The final goal of the Integrated Design process is to create buildings that are environmentally responsible, healthier to live and work in, and at the same time cost-effective. This needs careful consideration of the interdependency of building systems from the early stages of programming and design. Doing this requires a team structure that includes representatives from all disciplines, is flexible, and whose members are open to go beyond their comfort zone of routine working. The main elements of integrated design, according to the existing literature (7group & Reed, 2009; IEA, 2003; Kibert, 2008; Yudelson, 2008), are summarized in Table 2-1.

The literature review also revealed the gaps in knowledge about the Integrated Design process of SHP buildings. Indeed, the researcher found that no systematic evaluation framework exists to assess and measure the performance of integrated design teams in achieving integration.

Table 2-1. Critical Elements in the Integrated Design Process of SHP Buildings

Integrated Design factors
Early involvement of project parties
Communication and collaboration for problem solving and decision making
Early establishment of shared goals and priorities, especially with respect to environmental performance
Clear definition of performance targets
Commitment to integrated design
Eco-charrettes
Team composition and size (involvement of energy specialists, subject consultants, green design champions, contractors and subcontractors)
Presence of client as decision-maker in design process
Feeling valued and respected for all team members
Using iterative process in pre-design and schematic design phases to optimize system designs
Focus on optimization of whole building
Determination of tradeoffs and synergies between disciplines' decisions
Allowing time for feedback and revision before commitment to final design concept
Emphasis on commissioning and monitoring of project performance

3. RESEARCH METHODOLOGY

The purpose of this chapter is to explain the rationale for the specific research design that was adopted to achieve the research objectives. The present chapter begins with an overview of alternative research methodologies. Then, the chosen methodology and methods in this research and the logic behind adopting them are explained. Since a mixed-method (qualitative-quantitative) approach is adopted in the research, an overview of the qualitative and quantitative phases of research are then described. (Details of the activities of these two phases can be found in chapters 4 and 5, respectively). Finally, the efforts made to meet the validity criteria are discussed.

3.1. AN OVERVIEW OF METHODOLOGICAL ALTERNATIVES

Researchers use differing methodologies to seek answers to their questions. While it's beyond the scope of this report to cover all existing methodologies in detail, a brief overview would help clarify the position of the methodology and methods applied in the present research.

One of the most useful models for understanding various methodological alternatives for conducting research is the 'research process onion', proposed by Saunders et al (2009). As illustrated in Figure 3-1, the research process onion consists of six layers; each addressing one aspect of research methodology. The outer layer of the onion represents research philosophy or paradigm; the theoretical frame of reference through which we observe and understand the

world surrounding us (Babbie, 2010). Four major research philosophies include positivism, interpretivism, pragmatism, and realism. The philosophy of positivism relies on the accuracy, certainty, and objectivity of scientific knowledge (Crotty, 2003), seeking absolute truth through science. In contrast, interpretivism believes that multiple versions of reality can be equally valid (King & Horrocks, 2010) and that the social world is too complicated to be explained by scientific laws like those that govern the physical sciences (Saunders, Lewis, & Thornhill, 2009). Therefore, the interpretivist researcher tends to rely heavily on qualitative methods, rather than quantitative ones, to understand the dimensions of a social phenomenon.

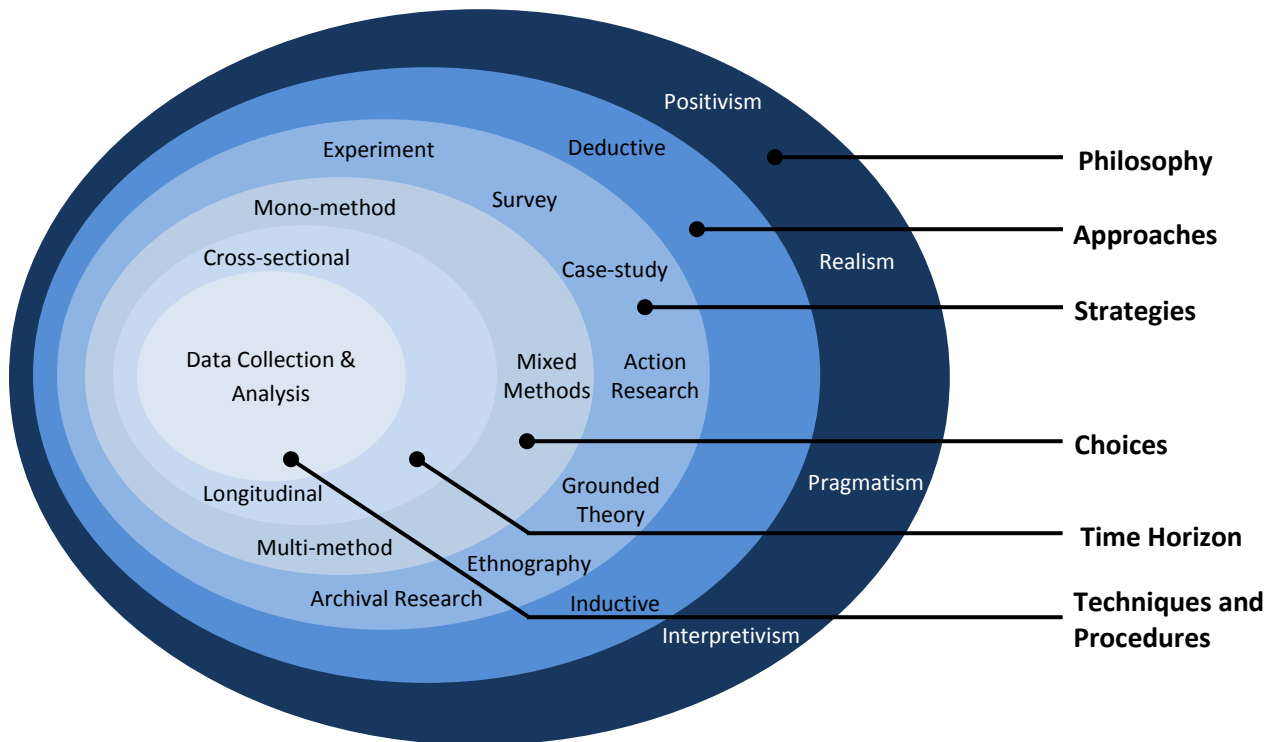


Figure 3-1. Research Process Onion (Saunders, Lewis, & Thornhill, 2009)

The philosophy of pragmatism holds that the research question is at the center of any research philosophy and thus that it is possible to apply various philosophies and methods together in order to develop the optimum method for solving the given question (Saunders, Lewis, &

Thornhill, 2009). Finally, realism, a research philosophy similar to positivism, believes that truth is what the human senses can perceive (Saunders, Lewis, & Thornhill, 2009).

The second layer of the research process onion is concerned with research approach. In this layer, two major approaches are presented: deductive and inductive. Using a deductive approach (theory-testing), the researcher generates a theoretical framework and then tests its hypotheses quantitatively using data (Creswell, 1994; Saunders, Lewis, & Thornhill, 2009). The inductive approach (theory-building), conversely, attempts to build theories by collecting and analyzing rich qualitative data.

The third layer, research strategies, concerns the overall plan that will be employed to answer the research questions. As Figure 3-1 shows, a variety of strategies can be applied for research purposes. Of these, both case-study and survey research are widely used in construction management research. The onion's fourth layer, research choices, represents the various methods available for research. Mono-method research choices are those that apply only one data collection and analysis technique, while multi-method research applies a mix of methods within either a qualitative or quantitative approach (Saunders, Lewis, & Thornhill, 2009). Finally, mixed-method research uses both qualitative and quantitative approaches to achieve its objectives (Saunders, Lewis, & Thornhill, 2009).

The fifth layer of the research process onion is concerned with the 'time horizon'; research can be either cross-sectional or longitudinal, depending on the time-frame within which data is collected. Finally, the sixth and innermost layer of the onion details techniques and procedures to collect and analyze data. Issues such as interviewing, sampling, and data cleaning belong in this layer.

3.2. CHOSEN METHODOLOGY

Various methodologies having been introduced, the chosen research methodology and methods in this research, as well as the rationale for choosing them, are explained.

Research in the field of construction management (CM) resembles social science and some scholars (Seymour & Rooke, 1995) attack the appropriateness of a mere rationalism paradigm (deductive; quantitative) in doing construction research. Instead, they support adopting interpretivism (inductive; qualitative) for this purpose (Seymour & Rooke, 1995). According to Seymour and Rooke (1995), positivism fails to take into account the judgment and perception of the people participating in research and, therefore, is an obstacle to effective research. Conversely, interpretivism seeks to understand the perspectives of research participants in a particular context, considering these an important element in social research (Seymour & Rooke, 1995). However, there are also CM researchers who strongly advocate positivism. Runeson (1997) argues that interpretivism has resulted in “no positive achievements” in the CM field and that positivism is still “the best way to reduce subjectivity and to discipline undisciplined researchers and the results”. Wing, Raftery, & Walker (1998) take a middle ground in this battle; they suggest adopting a pragmatic approach and choosing paradigms based on the nature of problems. They characterize construction management research as having a practical nature that requires generalizability of results and testing hypotheses (positivism) (Wing, Raftery, & Walker, 1998). Yet at the same time, they believe that interpretivism can be applied in certain problems, especially when seeking to understand human behaviors (Wing, Raftery, & Walker, 1998).

To clarify the position of the present research with respect to various research philosophies, it is worth repeating the research objectives mentioned in the first chapter. The current research has four specific objectives:

1. To identify the evaluation factors/items that could be used to measure the team performance in Integrated Design process of SHP projects;
2. To develop an evaluation framework for the ID process of SHP projects based on a systematic approach (CIPP);
3. To validate the proposed evaluation framework; and
4. To test the hypotheses that more integrated design teams are able to achieve more successful SHP project outcomes, great total LEED credits, and greater LEED credits in Energy & Atmosphere category.

The first two objectives involve understanding a phenomenon – i.e., the performance of integrated design teams of SHP projects -- within a social context, and developing a framework to evaluate it. Achieving these two objectives requires the involvement of various individuals' perspectives in producing the results (interpretivism). At the same time, the results must be validated and tested for generalizability, which makes adopting a quantitative positivism approach necessary in order to accomplish the third and fourth objectives. The present research, therefore, adopted a combination of research philosophies (pragmatism) and applied a mixed-method research strategy to seek answers for the defined problems.

This mixed-method research consisted of qualitative and quantitative phases. As the results of one phase (qualitative) functioned as the input to the next phase (quantitative), these phases were conducted sequentially. It is believed that combining qualitative and quantitative research

methods will result in a method that benefits from the “complementary strengths and non-overlapping weaknesses” of the two methods (Greene, Caracelli, & Graham, 1989).

3.3. QUALITATIVE RESEARCH

The objective of the first phase of this research was to generate a list of the factors, and their corresponding items, that could be used to evaluate the team performance in the ID process of SHP projects. Achieving this objective required an in-depth understanding of the research problem and its context, which was sought through qualitative research on selected case-studies.

Qualitative research is typically concerned with extracting in-depth information from small, “purposefully”-chosen samples (Patton, 1990). A study of the limited number of cases in a sample - case study research - begins with selection of the samples to be studied (Creswell, 2012). Sampling by case type is a common strategy; a case-study is selected for study because it represents an extreme case, intense case, typical case, unique case, reputational case, critical case, theory case, or a combination of these (McMillan & Schumacher, 1997).

For the purpose of this research, three SHP projects representing various levels of success in the Integrated Design process were identified through expert recommendations, and were selected as the cases to be studied. Studying these projects could identify the factors facilitating their design teams’ successes or challenges. Semi-structured interviews with participants were conducted as the data collection technique for the case-study research.

Moreover, a group of highly-experienced professionals in the field of Integrated Design were studied as they could provide invaluable information, gained through years of experience in the

field, about the Integrated Design process. For this purpose, 15 industry professionals with more than 10 years' experience in the integrated design who had also worked on LEED-rated projects were identified, approached, and interviewed using semi-structured questions.

The data collected in this phase were then coded, analyzed, and used in development of an evaluation framework for the ID process of SHP projects. This framework was reviewed by experts in order to assess its validity, redundancy, meaning, etc. The detailed activities of this phase and its results are described in chapter 4 of this report.

3.4. QUANTITATIVE RESEARCH

Creswell (1994) defines quantitative research as “an inquiry into a social or human problem, based on testing a hypothesis or a theory composed of variables, measured with numbers and analyzed with statistical procedures, in order to determine whether the hypothesis or the theory holds true”. As this definition suggests, quantitative research is important in determining whether a theory developed through a qualitative approach is true and, thus, generalizable.

Quantitative research was applied in this research in order to validate the proposed evaluation framework generated during the qualitative phase, and to test the research hypothesis. For this purpose, the evaluation items were incorporated into a questionnaire survey which was used as the data collection technique.

To design a quantitative study, it is important to set the target population, unit of analysis, unit of observation, and the sample size needed. The target population for the purpose of this research was Sustainable High-Performance (SHP) projects in the United States. Therefore, already-completed SHP construction projects in the US comprise the unit of analysis for the

questionnaire survey. Most SHP buildings in the US are recognized with LEED ratings due to the popularity of this rating system, its widely-spread application, stringent certification process, sustainability categories addressed, and number of projects rated under the system. Therefore the unit of observation – i.e., the appropriate unit for collecting information on units of analysis – was composed of the project participants of LEED-rated projects. These participants were used as the potential respondents to the questionnaire survey.

Since measuring all cases in a population would require significant time and financial resources, sampling is conducted as a cost-efficient and expedient method of data collection and the results are extrapolated to represent the entire population. Sample size is determined by balancing the four factors of finding accurate estimates: variability of sampling, feasibility, achievement of research objectives, and cost-efficiency (Dattalo, 2007). As explained in further detail in chapter 5, a sample size of 57 was determined necessary in order to achieve rigorous results in this research. This was ascertained based on the guidelines suggested by Green (1991), according to which the sample size for a regression analysis should exceed the number of predictors by 50. The sample frame adopted from which to draw the sample included several online professional groups, such as the 'LEED Accredited Professional' group on 'LinkedIn', a social networking platform for professional occupations.

Before distributing the generated questionnaire survey among the sample cases, it was first pilot tested on a limited number of academics and industry professionals. It was then revised, based on the feedback provided, and distributed. 79 responses were collected and their data analyzed using statistical analysis techniques.

To test the research hypotheses and study the relationship between variables, multiple regression analysis was applied. Regression analysis is type of statistical analysis that explores

the effect of one variable, independent variable, on another variable, dependent variable. In other words, it can measure the change in dependent variable when independent variable is changed. Multiple regression is type of regression analysis that incorporates several independent variables (which may be correlated (Wooldridge, 2009)) and measures the effect of each independent variable on the dependent variable, controlling for other independent variables. Structural Equation Modeling (SEM), another statistical technique capable of measuring the relationships between variables, is most appropriate in analysis of large sample sizes (usually with more than 200 cases) (Kline, 2005). An objective of the present research is to examine the relationship between integration and project outcomes; however since the sample size in this research is limited to 79 cases, multiple regression analysis was applied.

Chapter 5 explains in detail the activities conducted in the quantitative phase of this research.

3.5. ISSUE OF VALIDITY AND RELIABILITY

The purpose of validation in research is “to ensure that each phase of the chosen research methodology rigorously adheres to the highest standards of quality” (Lucko & Rojas, 2010). The literature highlights various types of validity. Some of the widely-mentioned types applicable to this research include: content validity, construct validity, internal validity, external validity, and reliability (Babbie, 2010; Bailey, 2008; Creswell, *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*, 2012; Hinkin, 1995; Yin, 2002).

Content Validity: This type of validity refers to the extent to which the content domains are covered and captured by the research (DeVellis, 2003), and the adequacy of this capturing (Hinkin, 1995). The evaluation framework generated through this research was developed based on interviews with industry professionals in the area of the Integrated Design process of

SHP projects. The literature support played a supplementary role in producing the results and ensured their adherence to theory. Moreover, content validity was further met by expert review of the evaluation framework, which ensured that all factors affecting the ID process have been captured and that the evaluation items are adequate to measure those factors.

Construct Validity: This aspect of validity concerns the theoretical association of a variable with other variables (DeVellis, 2003). Basically, construct validity tests whether the relationship of a variable of interest (integration, in the case of this research) with other variables (such as project outcomes) is in line with what the literature suggests. This type of validity can be tested through the empirical correlations of variables and examining if they “behave” similar to what the literature suggests (DeVellis, 2003). The quantitative study (statistical analysis) conducted as part of this research ensured achievement of construct validity.

Internal validity: This aspect of validity involves studying the research question under controlled conditions and ruling out plausible rival hypotheses (Rosenthal & Rosnow, 1991). In other words, internal validity evaluates the entire research design to determine if all variables that may affect the dependent variable have been considered. To meet internal validity, this research applied three strategies:

- a. All possible factors and variables potentially affecting the integration of project participants in the ID process of SHP buildings were investigated through literature review and qualitative research, and were included in the evaluation framework. In particular, the addition of contextual factors (such as complexity, sustainability, etc.) to the evaluation framework was intended to improve internal validity by capturing an aspect of change in project outcomes not related to the integration of project participants.

- b. The research results were compared with the literature findings to find contradictory results. Contradictory results are a measure of internal invalidity.
- c. Multiple regression analysis was conducted to examine the association of variables in the model .The results supported the findings of literature in the field.

External validity: This type of validity is concerned with the robustness of research and the generalizability of its findings to other samples (Rosenthal & Rosnow, 1991). A measure of external validity is representativeness (Babbie, 2010), whether or not the sample used for research is representative of the population of interest. This research relied on a sample of 79 projects which represented the characteristics of the population of LEED-rated projects with respect to location, size, cost, and certification level. Therefore, the issue of representativeness and external validity were met.

Reliability: This type of validity involves the consistency and repeatability of results using the same observations (Babbie, 2010). Although there are various measures for reliability assessment, internal consistency using Cronbach's Alpha is the most widely accepted measure (Hinkin, 1995). Due to some concerns about the appropriateness of Cronbach's Alpha for this purpose (refer to chapter 5 for further detail), it is employed in this study along with other measures, such as Inter-Item, Item-Test, and Item-Rest (or, Item-Total) correlations, to assess the reliability of the proposed evaluation framework.

The details of validity-checking activities are explained in further detail in the following chapters.

3.6. SUMMARY

This chapter reviewed some of the major research methodologies by providing an overview of the 'research process onion'. It was explained that a pragmatic approach combining positivism and interpretivism paradigms, deductive and inductive approaches, and qualitative and quantitative methods was applied in the present research; these choices could best address the research objectives.

The qualitative phase of this research included case-study research and interviews with professionals representing various disciplines involved in the Integrated Design process of SHP projects. The outcome of this phase was the development of an evaluation framework. The quantitative phase of research focused on validating the results and testing the research hypothesis using a questionnaire survey. The cross-sectional data collected through this survey on LEED-rated projects were analyzed using a multivariate regression analysis technique. Finally, this chapter examined the issue of validity and summarized some of the efforts made to meet its various dimensions.

4. DEVELOPMENT OF EVALUATION FRAMEWORK

Evaluation is performed to assess the merit, worth, and significance of a process, product, or project and its objective can range from improvement to accountability. The Integrated Design process of SHP buildings, like any other pursuit, should be evaluated by the owners or architects of these projects with the aim of complying with the best practices and detecting areas that need improvement. Moreover, evaluation provides project teams with the opportunity to benchmark their performance with past and future projects.

To develop a systematic evaluation framework for the Integrated Design process, an appropriate evaluation model must first be identified. A robust evaluation model guarantees that every important aspect of the phenomenon of interest is evaluated, and helps organize the evaluation factors and items. This is explained in detail in next section.

In addition, evaluation factors and items should be recognized in a systematic evaluation. An analogy may be useful in distinguishing evaluation factors and evaluation items. To evaluate human comfort in an architectural space, we may use a variety of criteria such as thermal comfort, visual comfort, psychological comfort, etc. These criteria reveal various aspects of comfort to be evaluated; these are 'evaluation factors'. Evaluation factors, however, are broad concepts that must be properly specified, or operationalized, so that we can measure them in a

valid and reliable way. For instance, two major indicators of thermal comfort that can be measured are temperature and relative humidity; these would be ‘evaluation items’. In the case of visual comfort, for instance, evaluation items would be illuminance (lux), luminance, etc. In other words, evaluation items provide tangible definition for evaluation factors and help measure them. Likewise, to evaluate the ID process of SHP buildings, a set of evaluation factors (such as systems-thinking, collaboration, etc.) and evaluation items to specify/operationalize those factors is needed.

Figure 4-1 shows a four-step methodology used in the first phase of this research, the qualitative phase, to develop the evaluation framework for the ID process of SHP projects.

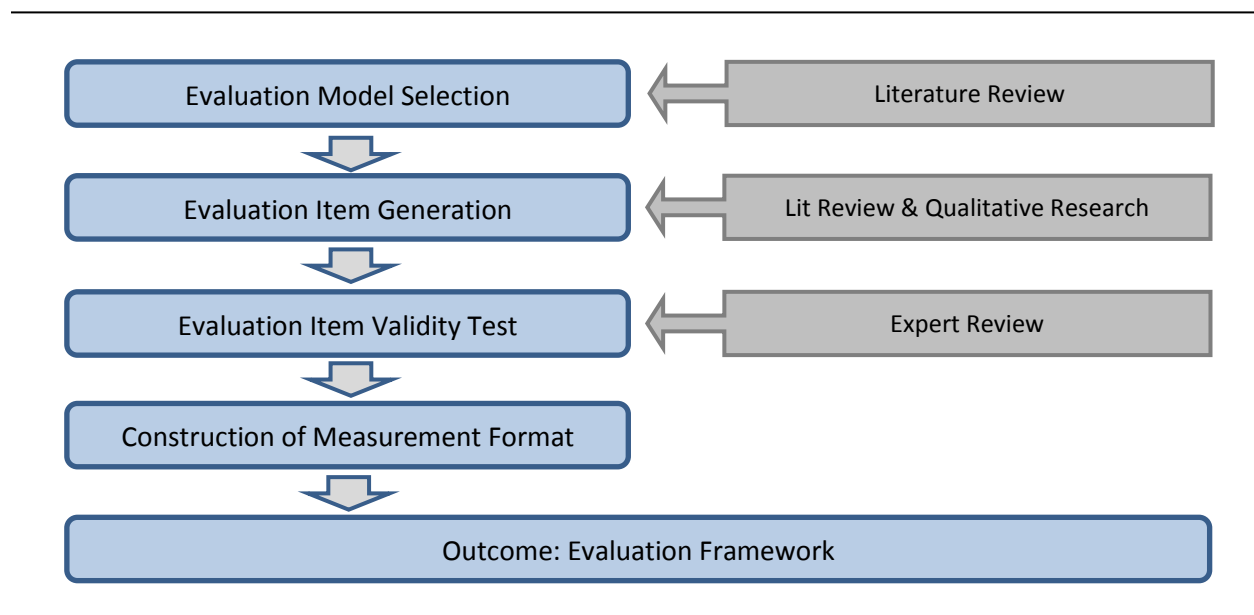


Figure 4-1. Methodological Steps in Evaluation Framework Development

4.1. SELECTION OF EVALUATION MODEL

The first step in designing an evaluation framework is to select an evaluation model to provide a structure for framing the questions and organizing evaluation factors and items. While there

exist some 26 evaluation approaches or models that are used to evaluate projects, services, etc. in various contexts and for different purposes, the Context, Input, Process, and Product (CIPP) evaluation model is considered the best of these with respect to feasibility, utility, accuracy, and propriety (Zhang, et al., 2011), and is used in practice for improvement and accountability purposes (Zhang, et al., 2011). Due to its comprehensiveness and other advantages, this model was selected for this research project.

The CIPP evaluation model was proposed by Stufflebeam (1983) and has been widely used in various contexts, especially in education and management, to evaluate the performance of programs, services, processes, projects, etc. Based on the CIPP model, evaluation is conducted through a “comprehensive framework” under the four categories of context, input, process, and product (Stufflebeam 2003, Stufflebeam & Shinkfield 2007). According to this model, context evaluation focuses on the needs, challenges, and opportunities within a defined environment that affect the performance of the process being evaluated. Input evaluation assesses the resources available and proposed strategies. Process evaluation focuses on the activities and factors critical to successful completion. Product evaluation determines whether the intended outcomes were achieved (Stufflebeam & Shinkfield, 2007). A major advantage of the CIPP model is that it provides the opportunity to assess a process, not merely at its end and based on its outcomes, but rather during the process and based on a combination of measures in addition to outcomes.

4.2. EVALUATION ITEM GENERATION

The next step in developing an evaluation framework was to generate a checklist of evaluation items to be used for the assessment of the ID process of SHP buildings. As mentioned before, evaluation factors represent various aspects of the subject of evaluation and evaluation items

provide tangible definitions for them. The subject of evaluation – i.e., the ID process and performance of integrated design teams - should first be broken down into evaluation factors, and then evaluation items measuring those factors should be identified.

In this phase of research, qualitative methods were used to supplement the literature review findings and help the researcher: a) identify evaluation factors, based on the CIPP evaluation model, to be used for evaluation of the ID process, and b) generate a checklist of evaluation items, or operational definitions, for the identified evaluation factors. Case-study research was used as the qualitative research method, and interviews with industry professionals were used as the data collection technique.

4.2.1. Data Collection

Case-study research was first used in the present research as the method of qualitative research in order to achieve in-depth insight about the research subject. Three examples of implementation of the Integrated Design process for Sustainable High-Performance Buildings were first selected as the project cases to be studied. These projects all adopted the Integrated Design in their design process and achieved various levels of success with respect to sustainability outcomes. The selection of these case-studies was based on reputation, media coverage and advice from the experts and they were studied in depth using archival data and semi-structured interviews with their key project parties.

The selected project case-studies represented three building types (office, research laboratory, and educational) of various floor areas and with various green certification levels (Living building, LEED Silver, and LEED Gold). Table 4-1 shows the characteristics of the case-studies. Extensive interviews were conducted with stakeholders of these projects to understand how their Integrated Design process functioned, what parties were involved in the design process

and at what point during the project, what factors facilitated success or inhibited it, and so on. The interviews were semi-structured, often taking place in respondents' offices and lasting about 1.5 hours. The objective was to characterize the Integrated Design process of SHP projects.

Table 4-1. Information on SHP Building Case-studies

	Green Rating	Floor Area (sf)	Construction Year	Building Type	Project Delivery
Case 1	Living Building	52,000	2013	Office	CM@R
Case 2	LEED Gold	196,845	2012	Educational	CM@R
Case 3	LEED Silver	77,000	2012	Research Lab	CM@R

In addition to project case-studies and interviews with their project parties, 15 industry professionals with extensive experience (i.e. more than 10 years) working as part of integrated design teams on SHP buildings were interviewed. These professionals represented major disciplines/parties present in the Integrated Design process of SHP buildings, including architecture, structural engineering, mechanical engineering, sustainability consulting, general contractors, and owners. Semi-structured interviews were conducted with these professionals to achieve insight on what major factors impact the design process and its success, obstacles and challenges, and so forth. By interviewing the professionals, the researcher also aimed at isolating some operationalized definitions, or evaluation items, for integrated design factors such as collaboration, systems-thinking, etc. Figure 4-2 illustrates the disciplines represented by the interviewees.

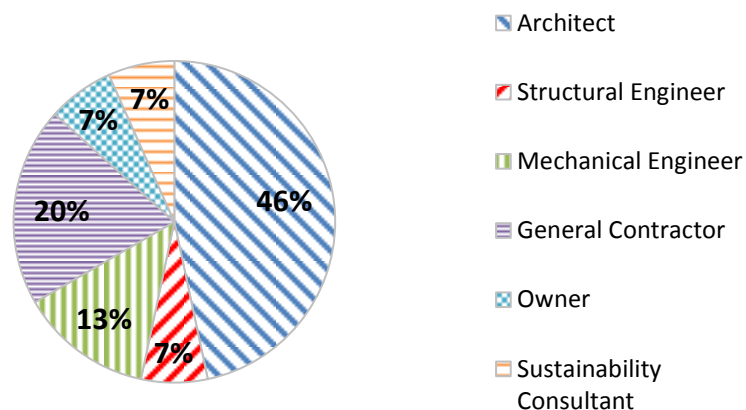


Figure 4-2. Disciplines Represented in Interviews

4.2.2. Qualitative Data Analysis Procedure

In qualitative research, data is analyzed with the purpose of discovering existing patterns in the data that build the theoretical understanding of a phenomenon (Babbie, 2010). A major consideration in data analysis is to take measures ensuring that the research procedure is repeatable and verifiable by other researchers. To this end, the interviews were first transcribed and then stored, coded, and analyzed in Dedoose (Lieber & Weisner, 2011), a web-based tool for analyzing qualitative and mixed-method research.

4.2.2.1. Coding and Content Analysis

Coding is a key step in qualitative data analysis; it is the process of classifying or categorizing data (Babbie, 2010) based on the themes, ideas, terms, phrases, etc. within it. To code the data in the present research, the interview transcriptions were read and labeled based on the themes present in the excerpts. For instance, if an interviewee suggested that the life-cycle impacts of a building should be considered in design decisions, this was recognized as an implication of ‘systems-thinking’ and was labeled and coded accordingly. Sometimes, one excerpt could be

labeled with multiple themes (co-occurrence). During the coding process the researcher performed constant comparison and pattern-matching to ensure consistency of coding throughout the data analysis and internal validity of the research. Table 4-2 illustrates the themes that emerged through the coding as well as the co-occurrence of themes. Colors have been used to highlight the frequency ranges for the coding: blue (0-10); orange (10-20); red (20-90); green (90+). Moreover, Figure 4-3 presents a content analysis of the themes.

Table 4-2. Co-occurrence of Factors in Qualitative Data

	Accountability	Collaboration	Collab. Goal & Perfor. Setting	Collaborative scope definition	Communication	Contractual support	Coordination	Decision-making	Early Involvement of Everyone	Inefficiency - Ineffectiveness	Leadership	Meeting - Colocation	Mindset	Owner - Clear expectations, etc.	Preparation for meetings	Previous experiecae	Success	System-thinking	Team Capability	Team Compatibility	Technology and Tools	Willingness to listen and explain	Totals
Accountability		3			3												2				5		13
Collaboration	3		7	6	25	1		1	14	1	9	8	9	9	5		9	35	10	5	11	3	171
Collaborative Goal and Performance Setting		7		5	2				2		2	2				6		1	7				34
Collaborative scope definition		6	5		2				5		2	3				3			7				33
Communication	3	25	2	2			3	1	9	1	3	4	2	4	3	1	6	19	7	3	9	5	112
Contractual support		1															1						2
Coordination					3				1								1	2	1				8
Decision-making		1			1				2		2	1						2	1			1	11
Early Involvement of Everyone		14	2	5	9		1	2			3	6		4	2	1	6	25	6	3	4	1	94
Inefficiency - Ineffectiveness		1			1													1	1				4
Leadership		9	2	2	3			2	3			1		4			2	8	7	2	2	1	48
Meeting - Colocation		8	2	3	4			1	6		1			3	2			6				1	37
Mindset		9			2														7	2	1	1	22
Owner - Clear expectations, etc.		9	6	3	4				4		4	3			2		1	9					45
Preparation for meetings		5			3				2			2		2				5	4				23
Previous experiecae					1				1														2
Success	2	9	1		6	1	1		6		2			1				6	3	3	4	2	47
System-thinking		35	7	7	19		2	2	25	1	8	6	7	9	5		6		12	3	9	1	164
Team Capability		10			7		1	1	6	1	7		2		4		3	12		3	1	1	53
Team Compatibility		5			3				3	2	1							3	3	3		3	28
Technology and Tools		5	11		9				4		2	1						4	9	1	3		49
Willingness to listen and explain		3			5			1	1		1	1					2	1	1	2			18
Totals	13	171	34	33	112	2	8	11	94	4	48	37	22	45	23	2	47	164	59	28	49	18	

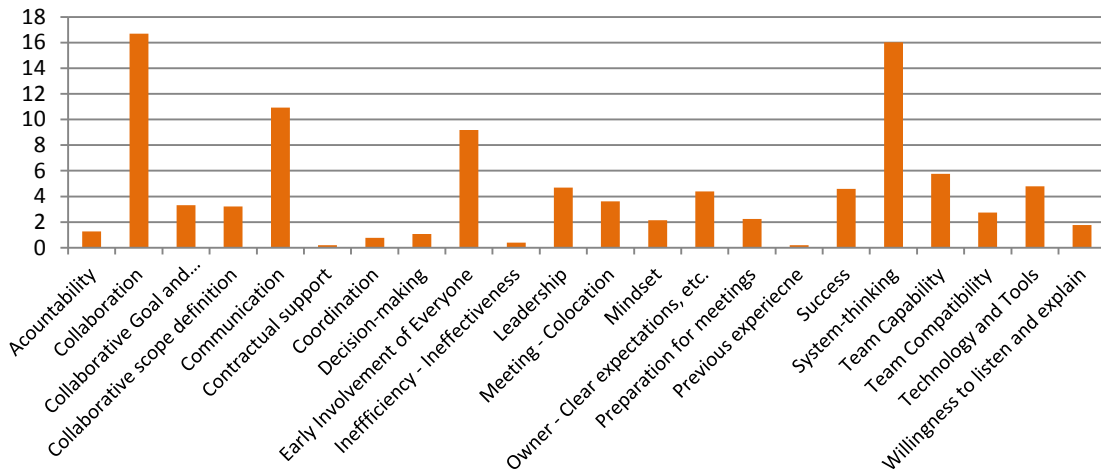


Figure 4-3. Share of Themes in Total Coded Excerpts

4.3. RESULTS & INITIAL POOL OF EVALUATION ITEMS

The results of qualitative research showed that a variety of themes, or factors, impact the success or failure of an integrated design team in achieving successful SHP buildings. As Table 4-2 indicates, the ‘systems-thinking’ theme/factor most frequently co-occurs, in the coded interview excerpts, along with collaboration, early involvement, communication, and team capability, respectively. Meanwhile, the occurrence of collaboration most often coincides with the systems-thinking, communication, early involvement, technology and tools, and team capability themes. In addition, as Figure 4-3 shows, about 17 percent of the themes that emerged in interview recordings corresponded to collaboration, followed by systems-thinking (16%), communication (11%) and early involvement (9%).

The data analysis revealed that collaboration, systems-thinking, communication, and early involvement of team members are the major pillars of the Integrated Design process. Project parties having previously worked together and contractual support were least mentioned in

interviews, but some interviewees insisted that these are critical factors in the success of integrated design teams.

In the next step of research, the themes/factors that emerged through qualitative data analysis as well as the factors identified by the literature review were organized into the CIPP evaluation model. Table 4-3 groups these factors based on their CIPP evaluation categories.

Table 4-3. Constituent Evaluation Factors of Developed Framework

Evaluation Category	Evaluation Factors and Sub-factors	
Context	Complexity (financial, temporal, technical)	
	Priority (cost, schedule, sustainability)	
	Uncertainty	
	Project Scope	
	Project Delivery Systems	
	Contractual Support	
Input	Project Budget	
	Team Capability	
	Tools	
Process	Collaboration	Accountability
		Commitment
		Communication
		Compatibility
		Involvement
		Joint Operations
		Mutual Respect
		Trust
	Leadership	Systems-thinking
Product	Cost Performance	Owner satisfaction
	Schedule Performance	Safety
	Sustainability Performance	Learning
	Innovation	Relationship Satisfaction

The evaluation factors in this model were then operationalized into the evaluation items. These evaluation items were identified by the researcher based on the interviews with industry experts as well as previous studies in the field. Some important issues considered in generating evaluation items included: reflection of the purpose, level of needed specificity or generality, clarity, validity, reliability, etc. (DeVellis, 2003). When writing the evaluation items for each evaluation factor, the qualitative data results were used to describe and properly specify how a certain evaluation factor could be captured in the context of the ID process.

In the following sections, the CIPP categories and their evaluation factors are described in the context of the ID process of SHP projects. Moreover, the evaluation items specifying evaluation factors are presented.

A. Context

Context evaluation, in the setting of the ID process of SHP buildings, is the assessment of a project's major challenges and opportunities potentially affecting the collective team's ability to achieve the intended outcomes. Contextual factors are usually out of the direct control of the design teams. Project complexity (financial, temporal, and technical), priorities (cost, schedule, and sustainability), uncertainty, project scope, project delivery systems, and contractual support are the major factors that fall in this category.

A. 1. Complexity

In a general setting, complexity is a characteristic of entities that are “dynamic, dissipative, non-linear, and self-organizing” and that contain “many interrelated elements” (Schalcher, 2009). Construction projects are by nature complicated and their complexity can be attributed to three major sources. Financial complexity stems from the uncertainty of outcomes due to technical

complexity and involves the difficulty in providing financial resources for a certain project (Remington & Pollack, 2007). Temporal complexity is concerned with unexpected environmental factors (such as weather conditions, legislative changes, etc.) that affect a project, while technical complexity results from the interdependency of design solutions (Remington & Pollack, 2007).

Design teams of SHP buildings usually face high degrees of complexity, especially the technical complexity involved with designing optimized energy-efficient building systems (heating, cooling, lighting, etc.). The higher levels of information needed to cope with these complexities require more integration among the team members. Financial, temporal, and technical complexity can be used as evaluation items to specify project complexity as a contextual evaluation factor. The following statements try to capture complexity and are used in the initial pool of evaluation items:

- Financial Complexity: The project is complex with respect to providing financial resources and paying the parties for their services.
- Temporal Complexity: The project is complex with respect to planning and timing of the execution of activities, given the environmental context.
- Technical Complexity: The project is technically complex, especially in terms of the building systems, project size, and the requirements of the project.

A. 2. Priority

Given the environmental, social, and economic factors surrounding a certain project, project owners choose to follow different priorities (Uher & Loosemore, 2004). The owners of SHP projects usually have different priorities with respect to cost, schedule, and sustainability goals based on their available resources, business goals, etc. The highest levels of challenge, as

related to project priorities, occur when cost, time, and sustainability are simultaneously prioritized by the owner. The following items can represent various aspects of priority as an evaluation factor and are used in the pool of evaluation items:

- Cost: Project cost is a major priority in this project.
- Schedule: Project schedule is a major priority in this project.
- Sustainability: Project sustainability is a major priority in this project.

A. 3. Uncertainty

Uncertainty refers to the gap between available information and the information needed to build a technical system (Galbraith, 1977) or to make decisions needed at a given point in time (Winch, 2010). The presence of uncertainties in construction projects poses risks to the owners and managers. Moreover, the natural complexity of SHP projects and the unpredictability of their outcomes create an uncertain environment that can potentially affect the working processes of the project team and the final results. The following evaluation item are used to capture uncertainty:

- There are high levels of uncertainty surrounding this project which posed project at high degrees of risk.

A. 4. Project Scope

Project scope, in broad terms, defines what is going to be developed, why, and how (ANSI, 2008), and in this way forms a basis for future decision making in a project. In other words, project scope is a written statement that determines the work's extent, based on the owner's needs and resources; sets the cost, time, sustainability, etc. objectives; provides the needed data; and establishes a preliminary budget for the project (Uher & Loosemore, 2004). The

extent to which a project's scope is defined before the architect is brought on board can influence the level of optimization possible, and can therefore impact the integrated design outcomes. The more completely the project scope is defined before the architect is brought on board, the less opportunity exists for optimization of various dimensions of the project, particularly with respect to sustainability. The following evaluation item is proposed to be used to capture project scope as a contextual evaluation factor:

- The project scope was fully defined before the architect was brought on board.

A. 5. Project Delivery Systems

Project delivery systems determine the relationships between participants in a construction project, the distribution of risks and responsibilities among them, and the phasing of the project delivery (AGC, 2012). Section 2.2.2 of chapter 2 examines the issue of project delivery systems in detail. The assignment of roles and responsibilities under more integrated approaches, such as Integrated Project Delivery (IPD), facilitates full collaboration among project parties while project delivery systems such as design-bid-build (DBB) do not encourage collaboration and integration of project participants. The ID process of SHP buildings can be facilitated by integrated project delivery systems such as IPD. The following item is suggested to be used to capture the context of the ID process with respect to project delivery:

- The roles and responsibilities of project parties are assigned under project delivery systems that support integration of project participants.

A. 6. Contractual Support

Contracts are a key tool to manage risk in construction projects. More integrated project delivery systems (such as IPD) tend to use types of contracts that bind the project parties together and share out the risks, savings, and overruns; these contracts foster collaboration and teamwork in

a green project (Yudelson, 2008). The context of the Integrated Design process with respect to contractual support can be measured by the level of agreement to the following statement:

- The type and terms of the contract support the integration of project parties and their full collaboration.

B. Input

Input evaluation, in the setting of the ID process of SHP buildings, is the assessment of the resources available to the project team to accomplish their assigned tasks. Project budget, team capability, and tools are three important resource categories that fall under this category of the CIPP evaluation model.

B. 1. Project Budget

Integrated design teams are usually provided with limited budget and expected to design buildings that have superior sustainability performance, compared with conventional buildings. When there is no balance between project budget and the expected outcomes, the integrated design teams face more difficulty in accomplishing their tasks. In such an environment, the design teams must find optimized design solutions (with respect to floor area, energy efficiency, daylighting, etc.) within the budget of the project. This in turn may affect the needed level of collaboration and integration. The following evaluation item can be used to capturing this issue:

- There is a balance between project budget and the expected outcomes.

B. 2. Team Capability

Capable project teams possess the needed resources (mainly, experience and expertise) to cope with the dynamic and complex conditions of SHP projects. Their members provide owners with sufficient and timely information for making decisions. Moreover, the owners of SHP

projects are resourceful enough to make needed decisions in a timely manner. Therefore, the following items can be used to operationalize ‘team capability’:

- The project owner is resourceful to make the needed decisions for this project in a timely manner.
- The team as a whole possesses sufficient experience and expertise for the design and construction of this project.

B. 3. Tools

Tools and technology play an important role in the success of an integrated design team. Indeed, building performance software should be applied in the schematic design process of a SHP project to assess the capability of a proposed alternative to achieve defined performance targets. In addition, Building Information Models should be applied during design and construction phases of a project to communicate the design, leading to a shared understanding of the project among team members. While there are other aspects to tools and technology (such as Last Planner System, etc.), the following evaluation items can sufficiently capture the maturity of integrated design teams in implementing technology:

- Building performance tools are widely used during the schematic design phase.
- Building Information Models are widely used in the design and construction phases.

C. Process

The third evaluation category, based on the CIPP model, is process evaluation; in the setting of the ID process of SHP buildings, this refers to the ways integrated design teams implement the inputs (budget, team capability, and tools) in order to achieve the products (i.e. project output).

Through the qualitative phase of the present project, the researcher identified the process-related factors that industry professionals believe are critical in the success of integrated design

teams. These factors were then operationalized through the interviews. Collaboration, along with its elements (such as communication, early involvement, etc.), leadership, and systems-thinking were agreed to be the major process-related factors in the ID process of SHP projects.

C. 1. Collaboration

As mentioned earlier, collaboration was the theme that emerged the most in interviewing industry professional about integrated design. Indeed, during an Integrated Design process, professionals of various disciplines and with different skills, interests, and cultures join a team and work together for the duration of the project. The industry professionals interviewed believed that the outcome of the team's collaborative effort is directly affected by the quality and culture of the team environment, chemistry among the members, and their behaviors and actions. When asked about collaboration in integrated design, an interviewee states:

“...I believe that the team dynamic on a personal level influences what actually gets built and so, to me, that's a very interesting idea, that personal interactions manifest themselves physically because I do believe that really happens. I think when you have good collaborative, and collaboration is a word that is overused, ... there's a very positive atmosphere and energy and people are working towards the same goal and people are respecting each other, the opinions of one another, you get a better building in the end because there is a synergy that happens on a personal level that results in better communication and better resolution of the design challenges and then that's ultimately what gets built and so the building is better. So, I actually think there is a relationship between the quality of the architecture and the quality of the personal relationships they went into....”

What most industry professionals seem to mean by collaboration is indeed joint collaborative operations that design team members carry out together, such as goal-setting, discussion for idea generation, and so forth. They also specified factors, such as communication or early involvement, that are categorized by the literature as sub-factors of collaboration. In line with what the literature suggests, all of these sub-factors were classified under the 'collaboration'

factor and then the qualitative data were used to delineate evaluation items for them. In the following sections, collaboration and its sub-factors are explained.

Collaboration has been widely scrutinized by the literature in various contexts. While English dictionaries refer to ‘collaboration’ as working together towards a goal (Oxford, 2012), collaboration is richer than mere teamwork and requires an environment of respect, trust, and free exchange of information to maximize the achievement of goals (Smyth & Pryke, 2008). Appreciating this richness, Wilkinson (2005) defines collaboration as “a creative process undertaken by two or more interested individuals, sharing their collective skills, expertise, understanding and knowledge (information) in an atmosphere of openness, honesty, trust and mutual respect, to jointly deliver the best solution that meets their common goal” (Wilkinson, 2005). Collaboration in construction occurs across organizational boundaries between owners, design team, contractors, etc. (Smyth & Pryke, 2008). While there exist many factors influencing collaboration in construction (Xue, Shen, & Ren, 2010), only those highlighted by the qualitative phase of this research as impacting the Integrated Design process were considered for the evaluation purposes of this research. These elements and their supporting literature are summarized in Table 4-4 and are further explored in following sections.

Table 4-4. Factors Affecting Collaboration in Construction Projects

Factor	Literature
Accountability	Chan et al (2004); Gabriel (1991); Yudelso (2008)
Commitment	Chan et al (2004); Yeung et al (2007); Yudelso (2008)
Communication	Hauck et al (2004); Diallo & Thuillier (2005); Yeung et al (2007); Yudelso (2008)
Compatibility	Kumaraswamy et al (2005)a; Kumaraswamy et al (2005)b; Xu et al (2005)
Involvement	Chan et al (2004); Yeomans et al (2006); Yudelso (2008)
Joint Operations	Chan et al (2004); Hauck et al (2004); Yeomans et al (2006); Yudelso (2008)
Mutual Respect	Forbes & Ahmed (2010)
Trust	Chan et al (2004); Cheung et al (2003); Diallo & Thuillier (2005); Kumaraswamy et al (2005)a; Kumaraswamy et al (2005)b; Wong et al (2006); Xu et al (2005); Yeung et al (2007); Yudelso (2008)

C.1.1. Accountability

Accountability is defined as “holding individuals and organizations responsible for performance” (Paul, 1991). To evaluate collaboration in a SHP project’s Integrated Design process, one criterion that needs to be evaluated is the degree to which the parties were held accountable.

The following is therefore added to the list of evaluation items to capture accountability:

- Team members are held responsible by the team leadership for timely completion of assigned tasks.

C.1.2. Commitment

Commitment refers to willingness to invest effort on behalf of the relationship (Porter et al., 1974). In the context of the ID process of SHP projects, various literature emphasize the importance of team members’ commitment to the process (7group & Reed, 2009; Yudelson, 2008; Kibert, 2008). This commitment, according to the qualitative research findings, can be evaluated on the basis of project parties’ patience in meetings and their willingness and lack of frustration in meeting the feedbacks. In particular, the following evaluation items aim to capture the level of commitment in an integrated design team:

- Project team members show patience and willingness during the team meetings to explain issues not clear to other parties.
- Project team members listen patiently and eagerly during the team meetings to the issues and concerns raised by other parties.
- Project team members do not get frustrated in addressing the received feedback on their work.

C.1.3. Communication

Communication facilitates the exchange of information among project parties. In the context of the Integrated Design process, communication becomes a crucial element of the process, especially when during design discussions (in or outside meetings) among various project parties. An interviewee refers to the importance of communication, stating:

“...we don’t go into our projects saying this is our way, this is the way it has to be; because ultimately this [integrated design] is about communication and it’s about people and different people have different talents, skills and ways of working. We work around the world, different cultures have a way of work and rather than saying here is our way, you have to do it this way, I’d rather come in and listen, kind of understand the process of what’s there and figure out how we can best contribute to that based on the resources we have; so that’s a little bit of the soft answer but it lets us be really successful...”

Another interviewee mentions:

“...The most important thing is they [team members] have to like to working with people and, I think, people have to recognize how difficult communication is so that they work on being clearer and don’t get frustrated when something isn’t clear...”

Communication also becomes important when the outcome of the design process should be exchanged among the team members. The qualitative research suggests establishing a clear and easy-to-understand protocol for communication among team members, especially with respect to sharing and updating documents, models, etc., to avoid confusion and conflict. Building Information Modeling can be an important platform for achieving a shared understanding of the project and to facilitate communication among various parties.

In the literature review, communication emerged as a key collaborative element in organizational success (Wu, 2009). Quality of communication is determined by the timeliness, adequacy, accuracy, and credibility of the information exchanged (Mohr & Spekman, 1994). In the context of SHP projects, BIM model implementation can be a measure of the accuracy, adequacy, and credibility of information.

The following evaluation items were added to the checklist in order to capture 'communication' maturity as an evaluation factor:

- The project goals are communicated effectively among the project team members.
- The team have regular formal meetings and they can readily reach others formally or informally when needed.
- The team members attend the meetings prepared.
- The team members spend their meeting times critically engaged in exploring and evaluating solutions to the design problems.
- The team members are able to get needed information in the least possible time through formal means of communication (email exchange, phone calls, etc.).
- There is a strict but easy-to-use protocol in place for sharing and updating the documents, drawings, models, etc. among project parties, which prevented confusion and conflicts.

C.1.4. Compatibility

Integrated design teams comprise professionals of various disciplines, which often have disparate languages and cultures. To work effectively in this environment, team members should possess flexibility and willingness to adapt to a project's environment; incompatibility is believed to be a barrier to team integration in construction projects (Kumaraswamy et al., 2005a). Qualitative data analysis suggested that having prior working experience with other parties can be a boon to achieving this compatibility. Therefore, the following items are suggested to be used for evaluation of compatibility:

- The team members are familiar with each other through previous work or reputation.
- The team members are compatible at both personal and organizational levels.

C.1.5. Involvement

Early involvement of project stakeholders is necessary in the Integrated Design process, primarily to facilitate the exchange of information, identify the major issues to be addressed by the design team, and consider the impact of design alternatives on the areas represented by the stakeholders. The interviews conducted with industry professionals suggested that early involvement of contractors, maintenance crews, suppliers, estimators, and users are of special importance in order to consider different points of view and achieve a mutual understanding of project objectives. As one interviewee states: "...The primary thing [in integrated design] is to engage everyone in everything early....".

In the context of the ID process, early involvement of project parties has been well-justified on the grounds that timely provision of needed information enhances decision making (Yudelson, 2008; 7group & Reed, 2009). The examination of case-studies and qualitative data suggests that the quality of project parties' involvement is dependent on the number and type of disciplines involved, the timing of their involvement, and their level of active engagement in the design process. Therefore, 'involvement' as an ID factor can be best evaluated through the following evaluation items:

- The project owner, or its representative, is actively involved throughout the design process.
- In addition to the architect and the owner, representatives of following disciplines are **present** in the team and **actively engaged** in the design process: civil engineering,

structural engineering, mechanical engineering, electrical engineering, lighting design, plumbing engineering, cost estimating, general contractor, major trade contractors, major suppliers, users.

- The addition of representatives of the following disciplines to the team happens in a **timely** manner during the design process: civil engineering, structural engineering, mechanical engineering, electrical engineering, lighting design, plumbing engineering, cost estimating, general contractor, major trade contractors, major suppliers, users.

C.1.6. Joint Operations

‘Joint operations’ concerns the major macro-level activities that an integrated design team carries out during the design process in order to accomplish its task of designing an SHP project. These activities include team selection, goal-setting, performance target-setting, idea generation, design iteration, and design evaluation. Thus, in order to evaluate how successful an integrated design team is in operating jointly, the following evaluation items need to be assessed:

- Consultants, subcontractors, suppliers, and vendors are selected to join the team based on the inputs of the core team.
- The team members collaboratively set time, cost, and sustainability goals.
- The team members collaboratively set performance targets to meet the defined goals.
- Many innovative ideas with respect to sustainability issues, form, program, value-adding, etc., are generated during the joint meetings.
- The team collaboratively produces several design alternatives based on the jointly-generated ideas and revises/refines them based on the inputs of team members.

- Before selecting the final design, the design alternatives are discussed by the team and their achievement of performance targets is evaluated.

C.1.7. Mutual Respect

Mutual respect is believed to be an important driver of collaborative working and integration in construction (Baiden et al., 2006; Wu, 2009). It is also a factor contributing to the success of relationships (Frei & Shaver, 2002). The qualitative research findings suggest that mutual respect is achieved when there is concern and sympathy for others and team members feel valued; this makes them go beyond their obligations in responding to requests. Mutual respect, as an evaluation factor, can be captured through the following evaluation items:

- The team members are sympathetic towards other parties' situations.
- Project team members go beyond their obligations in meeting other parties' requests.
- The team members feel valued by other team members.

C.1.8. Trust

Numerous definitions of trust have been offered by literature in various fields. James (2010) compiles a list of these definitions along with several theoretical and empirical models of trust (James, 2010). One definition, offered by Mayer & Davis (1995), defines trust as “the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor” (Mayer & Davis, 1995). The semi-structured interviews with industry professionals as well as the literature review revealed that the project parties of SHP projects expect other parties in an integrated design team to perform a number of actions, or possess some attributes, in order to characterize the team environment as one with sufficient trust:

- The team members are confident they will receive valid information from other parties at the right time without too much effort.
- The team members believe in the capabilities of each other and the team.
- The team members are confident that their voice will be heard and the project team's decisions will reflect the concerns of everyone on the team.
- The team members are confident that the project team's decisions will be the most beneficial for the project and for the team.
- The team members are confident that no one on the team will take action against the interests of others to achieve what he wants.
- The team members are confident that all parties will be transparent in their communication with other parties.
- The team members are confident that the team has made or makes sufficient efforts to examine all potential solutions to the design problem.

C. 2. Leadership

Through interviews with industry professionals, the researcher learned that for many professionals the Integrated Design process is primarily a management exercise in capability to make decisions at the right time. According to the interviewees, teams benefitting from stronger leadership and management skills achieve collaboration and systems-thinking more readily. To succeed, the owner and architect should be wise enough to bring in the right consultant at the right time, leading the whole process and making fast stable decisions early.

When asked about the role of leadership in the Integrated Design process, an interviewee who had facilitated the design process of many green projects as the owner's representative and sustainability consultant, stated:

"...[during the design process], I ask how is everyone's morale, is this process working for you architect, are you okay with how we are sharing information, what's missing, is there any other ideas anyone has. I will challenge them like how do we squeeze 2% more out of energy. Are you getting information that you need in a timely manner, am I giving you decisions in a timely manner or are you guys kind of in limbo right now, what do you need from me to make you successful, that's the kind of question I will ask them. Ultimately, my job is to make them and the project successful, so it's not just I am the owner giving orders. I am also supporting this team and the construction process to make sure everyone is successful. I ask if there is anything they would have changed, so I get feedback on my ability to manage a team."

Without strong leadership the integrated design cannot be successful. An interviewee mentions:

".....There is a fallacy in that process though. On a project, we just told them [owner] not to do it [integrated design process]. We said we can do it, we know how to do it, happy to do it, but what I can guarantee on that project, the owner in that case, can't make decisions fast enough to warrant having that many people sitting in the same room waiting for a decision to happen. So what you are going to have is a lot of people twiddling their thumbs without something to do because the decision process won't happen fast enough....But for many of our projects, unless it's someone who really knows what they are doing on the ownership side and make decisions, it [integrated design] is a little too much horsepower not really doing anything..."

Literature in the field views leadership as an important function of management in construction projects, which drives innovation (Bossink, 2004). Leadership is defined as "the ability of an individual to influence, motivate and enable others to contribute toward the effectiveness and success of the organizations of which they are members" (Simonton, 1994). It has the ability to affect culture, form, and practices in an organization (House et al., 2002).

In the context of the ID process of SHP projects, owners can provide leadership by aligning the resources, motivating the team, and making fast and stable decisions to support future steps of the project. Leadership, as an evaluation factor, can be evaluated using the following items:

- The owner possesses the required capability and makes sufficient efforts in setting directions and aligning team resources for the project.
- The owner possesses the required capability and makes sufficient efforts in motivating the team members, fostering a sense of ownership, and building trust among them.
- The owner possesses the capability to make fast and stable decisions based on the input of the design team.

C. 3. Systems-thinking

The qualitative data analysis suggested that integrated design teams should embrace systems-thinking by considering the performance of a project over a complete life-cycle and across disciplines. Building performance tools should thus be applied widely before the selection of the final design, allowing the project team can make the optimum design decisions.

As previously mentioned, the theme of systems-thinking in conversations with interviewees often emerged alongside the collaboration theme. One interviewee even implied that collaboration is a pre-requisite to systems-thinking: “my sense is that if somebody on the team is geared toward collaboration, the systems-thinking will follow.” When asked about how systems-thinking in practice is achieved in the design process, another interviewee mentions:

“You do a bio-climatic analysis and you have what we call the discovery phase. So what are all the available incentives? What are all the available resources on that site? What is the solar income? What is the wind income on that site? What is the habitat like? What was it like before it was developed? What is the ecological water flow? What are the available resources that we can utilize on this site that can be used in the building? What

is adjacent to that building? Is there any ways to heat the building from next door? So, do like a lot of fact-finding, get a lot of data and put it in place and identify champions who can oversee aspects regarding energy. So you define the goals upfront, you assign someone to manage that goal through the project for energy, water, habitat, materials whatever it is so that someone is responsible for that and you have these kind of iterative cycles of integrated design meetings and then do diligent design, come back to whole systems meeting, come back you know further refine it in whole systems meeting until you design the maximum goals....”

The need for systems-thinking in the Integrated Design process stems from the need to consider the interaction and interdependency of building, humans, and environment. This interdependency should be understood and examined in all life stages of a building and across disciplines involved in the design, construction, and operation and maintenance phases of a construction project. Based on the qualitative research results and literature review, the following evaluation items are suggested to be used to assess ‘systems-thinking’ in the ID process:

- The tradeoffs and synergies of the following major sustainability elements are thoroughly discussed in the joint meetings before making design decisions: form and energy use, site potentials and energy use, site potentials and daylighting, site potentials and ventilation, daylighting and energy use, ventilation and energy use, etc.
- Impacts of design decisions across relevant disciplines are discussed before making decisions.
- Impacts of design decisions over the project lifecycle are discussed before making decisions.
- The team as a whole is motivated to achieve sustainable design and follow opportunities for that through exploration and discussions rather than mere pursuit of LEED credits.

D. Product

Product evaluation, the final category of evaluation factors in the CIPP model, refers to evaluating the outcome of the ID process with respect to the defined project goals. Performance of a SHP project is often evaluated in terms of cost, schedule, sustainability, quality, customer satisfaction, safety, and innovation. In the United States, success in achieving sustainability is usually defined on the basis of LEED certification level. The researcher adds 'relationship satisfaction' and 'learning' to the list of product evaluation items in order to capture the aspects of success concerning the team parameters, rather than the building:

- Cost: Project was successful in exceeding the cost targets defined in the initial contract.
- Schedule: Project was successful in exceeding the schedule targets defined in the initial contract.
- Sustainability: Project was successful in addressing sustainability based on LEED certification level.
- Sustainability: Project was successful in addressing sustainability compared with other LEED-rated projects.
- Innovation: The project is innovative at the time of design/construction, compared with the regular practice in the market.
- Owner satisfaction: The project owner is satisfied with the final outcome of the project.
- Safety: Compared to similar projects, high levels of safety were achieved.
- Learning: Being part of this project improved the learning by project parties.
- Relationships: Team members are satisfied with the quality of relationships during design phase, and relationships survived following the completion of the project.

4.4. EVALUATION ITEM VALIDITY CHECK

The next step in methodology, following the generation of evaluation items, was to check their validity. Validity in general refers to the ability of evaluation items to measure what they intend to. To make an analogy, a light meter is not a 'valid' tool for measuring temperature while a thermometer is, because a light meter is incapable of capturing temperature. Content validity, as one type of validity, reflects the extent to which the evaluation items cover the content domains (DeVellis, 2003). In this phase of research, content validity was checked by testing whether the evaluation items generated can capture, or measure, the ID process of SHP buildings.

In the present research, the researcher was confident that a degree of content validity was extant in the evaluation items because existing literature had contributed to development of the list of items. To further assess the content validity of the items, however, the list was extended to a group of experts (both industry and academic) in the field of the Integrated Design process of SHP buildings. The experts were asked to check whether the list covers various aspects of the ID process and whether the evaluation items can properly assess those aspects, to make suggestions for items to add, eliminate or reword, and to provide general feedback on the list. The experts in general were pleased with the evaluation framework, but they also provided two specific comments on the list. The final list of evaluation items was developed by addressing these comments and adding two evaluation items to the list. The first comment concerned the effect that inclusion of sustainability requirements in the contract terms and conditions would have on encouraging collaboration among the design team. The second comment sought to include evaluation items to capture the aspect of leadership provided by the architect. To address these comments, the following items were added to the initial list:

- Sustainability requirements and goals for the project are integrated into the contract.

- The project architect possesses the capability to predict design issues needing addressing in a timely manner, invite appropriate participants at the right time, and effectively engage participants in team discussions.
- The project architect possesses the capability to lead the design team by communicating and pursuing the project goals and targets.

The resultant final list of evaluation items included 65 items organized into the four categories of Context, Input, Process, and Product, based on the CIPP model of evaluation. For a complete list of the items, refer to Appendix A of this manuscript.

4.5. CONSTRUCTION OF MEASUREMENT FORMAT

The final step in developing the evaluation framework was to design a measurement format for quantifying the results of evaluation. Quantification of the evaluation provides the opportunity to compare the performance of integrated design teams across projects and associate their performance with project outcomes.

In designing the measurement format, first a response format for evaluation items was provided and then a simple mechanism for scoring and indexing was designed. The response format would show the evaluator various degrees of an evaluation item and allow the evaluator to choose the one among them that best reflects the subject of evaluation. Likert-scale is one of the most common response formats used in various studies (DeVellis, 2003); therefore this scale was used as the response format for the evaluation framework of this research. The points in this scale represent various degrees of agreement with the declarative statement of the evaluation item. A 5-point Likert-scale provides the highest reliability and is the most widely used type of Likert-scale in the scale development literature (Hinkin, 1995). Accordingly, a 5-

point scale was used with the degrees of 'strongly disagree', 'disagree', 'neutral', 'agree', and 'strongly agree'.

The next issue in measurement is scoring and indexing. Since hypothesis-testing was a future step in this research, the evaluators' scores on the evaluation items needed to be aggregated into indices that could quantify the performance of teams under each category of the CIPP model. To this end, one important issue was the 'weighting' of evaluation items with respect to their importance in evaluating the ID process of SHP buildings. In other words, it had to be decided whether the evaluation items had equal weights or different weights with respect to their importance in measuring the subject of evaluation. While there is no firm rule as to weighting, the literature in the field recommends equal weighting of evaluation items unless there are compelling proved reasons to use of differential weighting (Babbie, 2010). Moreover, equal weighting can be considered objective because the subjectivity of the researcher with this method remains limited to the influence of the subject matter experts on selection of evaluation items (Maggino & Ruviglioni, 2009). For the purpose of the evaluation framework developed in this research, equal weighting was used for two reasons: 1. There is no literature and theoretical framework in the field supporting the difference of the evaluation factors identified in this research, such as trust, mutual respect, collaboration, etc., with respect to their significance or importance. 2. Equal weighting improves the objectivity, simplicity, and robustness of the developed evaluation framework.

With equal weighting, and assigning the scores of 1, 2, 3, 4, and 5 to 'strongly disagree', 'disagree', 'neutral', 'agree' and 'strongly agree', respectively, the following equations can be applied to construct the indices of interest. Three indices can be built in this way: a) Challenge Index (CI) representing challenges arising from the context of a project; 2) Integration Assessment Index (IAI) representing input and process categories which would show the level

of integration maturity; and 3) Performance Index (PI) representing the product category. The following equations were used for building these indices:

Formula 1: $CI = \sum(S_c - (S_{c.pds} + S_{c.cont}))$

Formula 2: $IAI = \sum(S_i + S_{ps})$

Formula 3: $PI = \sum S_{pt}$

Where,

- CI, IAI, and PI refer to Challenge Index, Integration Assessment Index and Performance Index, respectively;
- S_c refers to all evaluation items in the context category; excluding those that address project delivery systems and contractual support;
- $S_{c.pds}$ and $S_{c.cont}$ represent the project delivery system and contractual support evaluation items, respectively;
- S_i , S_{ps} , and S_{pt} represent the scores assigned to the evaluation items in the input, process, and product categories, respectively. (See Appendix A for the list of evaluation items).

The minimum value for each index can be determined by using these formulas and assigning a score of 1, which represents 'strongly disagree', to all evaluation items in the category, or categories, covered by that index (refer to Appendix A for the list of evaluation items). This leads to the minimum values of -7, 45 and 9 for the Challenge Index (CI), Integration Assessment Index (IAI) and Performance Index (PI), respectively. Likewise, using a score of 5 (for 'strongly agree') results in the maximum values of 37, 225 and 45 for CI, IAI, and PI, respectively. The performance of a given project on these indices would vary within the range between minimum

and maximum values. To rate projects based on their performance on the three constructed indices, the ranges of indices were translated into several intervals, as shown in Table 4-5.

Table 4-5. CI, IAI and PI Indices and their Ranges

Challenge Index (CI)		Integration Assessment Index (IAI)		Performance Index (PI)	
Extremely Challenging	29-37	Extremely Integrated	190-225	Extremely Successful	39-45
Moderately Challenging	20-28	Moderately Integrated	154-189	Moderately Successful	32-38
Somewhat Challenging	11-19	Somewhat Integrated	117-153	Somewhat Successful	23-31
Mildly challenging	2-10	Mildly Integrated	81-116	Mildly Successful	16-22
Not challenging	-7 to1	Fragmented	45-80	Unsuccessful	9-15

4.6. SUMMARY

The present chapter attempted to describe the process of developing a framework for evaluating the ID process of SHP projects, and explain its structure. Figure 4-4 illustrates this framework and its components. The major components of this framework are as follows:

- a. **Evaluation Model:** Context, Input, Process, and Product (CIPP) model
- b. **Evaluation Factors:** See Table 4-5
- c. **Evaluation Items:** See Appendix A
- d. **Measurement:** Challenge Index, Integration Assessment Index, and Performance Index

The developed evaluation framework was founded on the CIPP model of evaluation, which assesses a project based on its context-, input-, process-, and product-related factors and

items. For the purpose of this project, context evaluation comprises complexity, priority, uncertainty, project scope, project delivery system, and contractual support in an SHP project. Input evaluation assesses project budget, team capability, and tools. Process evaluation focuses on collaboration, leadership, and systems-thinking. Finally, product evaluation assesses cost, schedule, sustainability, and other aspects of the performance of a SHP project. Figure 4-4 provides the complete list of the factors and sub-factors and Appendix A lists the 65 evaluation items along with their associated evaluation categories and factors.

In addition, the evaluation framework includes a measurement model to quantify and aggregate the results of evaluation into three indices, a Challenge Index (for context category), an Integration Assessment Index (for input and process categories), and a Product Index (for product category); each with a spectrum of low to high values. These indices provide a basis to compare SHP projects and their integrated design teams based on three indices. It also allows for potential empirical studies on the association of IAI and other indices. Construction of these indices was based on equal weighting of the evaluation items.

In the next phase of research, as explained in next chapter, the proposed evaluation framework was validated using a quantitative study and the association between these indices were explored.

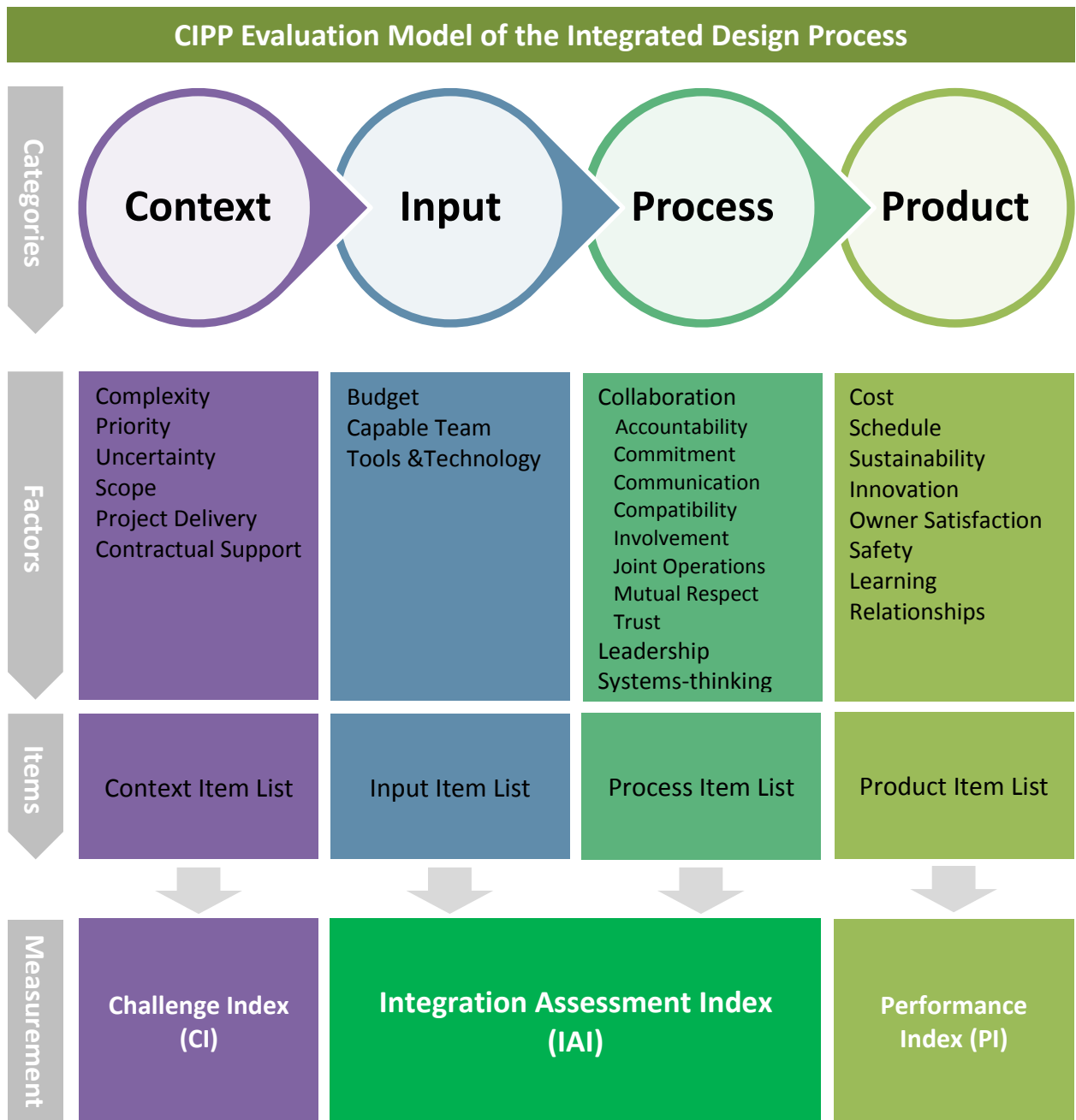


Figure 4-4. CIPP Evaluation Model for the Integrated Design Process of SHP Projects

5. VALIDATION & HYPOTHESIS TESTING

The evaluation framework developed in previous phases of this research validation; this is an important step in research design that attempts to evaluate: a) whether the research instruments are indeed measuring the concept of interest in the research, and not some other concept (Bailey, 2008), and b) whether the research findings are accurate (Bailey, 2008; Creswell, 1994).

In chapter 3, the measures this research has taken to meet the validity criteria in qualitative research were explained. This chapter focuses on validating the results for construct and external validity and reliability using quantitative research. The quantitative data were also used for testing the research hypothesis that: 'more integrated design teams are able to achieve more successful SHP project outcomes'.

5.1. QUESTIONNAIRE SURVEY DEVELOPMENT AND DEPLOYMENT

As mentioned above, quantitative research could be used to test the evaluation framework's adherence to validity criteria and determine whether it functions in practice. For this purpose, a cross-sectional questionnaire survey and statistical analysis of its data were designed and conducted.

5.1.1. Unit of Analysis and Observation

The first step in developing the questionnaire survey was to determine the unit of analysis and unit of observation. Since the focus of this research is on Sustainable High-Performance (SHP) projects and the performance of integrated design teams, the appropriate unit of analysis for the questionnaire survey is SHP construction projects. As mentioned in the literature review chapter, a variety of rating systems, such as LEED, BREEAM, etc., exist to rate and label SHP projects. While it can be argued whether the buildings labeled under these rating systems actually do achieve their sustainability targets, these buildings are currently the only resources available for research purposes. Due to the popularity of the rating system in the United States, its widely-spread application, its stringent certification process, the sustainability categories addressed, and the number of projects labeled under the system, only LEED-rated projects were selected as representative of SHP projects for this phase of research.

The unit of observation in this project is the project participants of LEED-rated projects who were used as the potential respondents of the questionnaire survey in order to collect information on LEED projects.

5.1.2. Questionnaire Development

Survey research, particularly a questionnaire survey, collects data from a sample through a cross-sectional or longitudinal study with the objective of generalizing the results of the analysis to a larger population (Babbie, 2010). This type of research provides a quantitative portrayal of the trends or opinions of a population through studying a sample of that population (Creswell, 2012).

In the present research, a cross-sectional questionnaire survey was adopted and the questionnaire was designed to collect information about LEED-rated projects, as a representative of Sustainable High-Performance (SHP) buildings. The questionnaire attempted to collect information on project attributes, integrated team-related characteristics, and project outcomes (time, cost, and sustainability).

The questionnaire was designed based on the evaluation framework developed in the previous phase of research. Moreover, it was designed to be distributed among the project participants of LEED buildings while allowing them to remain anonymous; anonymity increases the chances of receiving candid information about unsuccessful projects and minimizes respondents' exposure to any potential risk. In this way, the requirements of the Human Subject Division at the University of Washington were also satisfied.

Questionnaire respondents were asked to provide information about an already-completed LEED-rated project, as the frame of reference for their responses. The rationale for targeting already-completed LEED-rated projects was that on such projects, respondents would be able to provide complete data and information on various aspects of project, such as project cost, time, etc. The questionnaire items sought to unearth the facts and opinions of respondents about the project.

The questionnaire consisted of 5 sections. The first section requested general information about the project and asked which party (architect, general contractor, etc.) the respondent represented. These questions were designed to collect factual information about the project. The second set of questions requested information about the context of project with respect to the level of complexity, priorities, project delivery type, etc. The third set of questions sought to capture the extent to which the project team possessed the resources necessary to perform the

assigned tasks. The fourth set of questions asked respondents to provide their opinion on the level of maturity of the Integrated Design process and team-related issues. The final section asked respondents questions about their perception of the project's success and attempted to understand whether the project was successful in achieving its objectives. The content of the questions reflected the evaluation items in the evaluation framework, and the response format for the last four sets of questions was based on a 5-point Likert-scale, representing various levels of agreement with each evaluation item statement.

The questionnaire was prepared in the 'WebQ' online format (UW, 2012), an online survey tool provided by the University of Washington for use by students, faculty members, and staff. The format and layout of the questionnaire were given sufficient consideration to maximize responses and avoid unintentional miss of questions. The questionnaire was now ready for pilot testing.

5.1.3. Pilot Testing and Questionnaire Revision

Pilot testing of the questionnaire was conducted to evaluate its clarity, validity, comprehensiveness, and feasibility. Three Ph.D. students, two faculty members, and all participants of the qualitative phase of research who had already been interviewed were provided with a link to the online survey and were asked to provide their feedback and comments. Appendix B includes the questions used in pilot testing the questionnaire.

The received feedback reflected general satisfaction about the topics covered by the questionnaire survey but also illuminated a major area for improvement. Indeed, some respondents complained about the length of the survey and the long time required to complete it. This is a very important issue in survey design; long surveys can result in respondent fatigue and reduce the response rate, and therefore can negatively impact the ability to make

inferences about the population of interest. However, it is important to distinguish here between the purpose of the evaluation framework and that of the questionnaire survey. The purpose of the evaluation framework is to aid owners or architects of SHP projects in self-evaluating their ID process. For that purpose, a lengthy evaluation framework would not be an issue, as those evaluators would be willing to spend a maximum of 1 hour of their time in order to detect potential issues with their process. In contrast, the purpose of a questionnaire survey is to collect data and conduct research that may or may not interest the respondent. Therefore, the length of a questionnaire survey should be optimized such that it does not cause respondent fatigue and subsequent problems with respect to research results, and yet doesn't compromise the validity and reliability of research.

Therefore, the questionnaire survey was revised and re-designed in order to reduce its length without compromising its validity. This process included rewording some questions and merging some others. Moreover, some questions covering product category were removed from the survey to further reduce its length. The remaining questions related to product category, however, were sufficient to capture major project performance dimensions including cost, schedule, sustainability, innovation and safety. The revised survey was now ready to be deployed.

5.1.4. Sampling Design

Since measuring all cases in a population would require significant time and financial resources, sampling is conducted as a cost-efficient and quick method of data collection, the results of which can be substituted for a measurement of the entire population. The sampling process consists of the following stages (Diamantopoulos, 2000): defining the population, specifying the sampling frame, choosing the sampling method, determining the sample size, and sample drawing.

As mentioned earlier, the population of interest in this phase of the research was Sustainable High-Performance (SHP) construction projects; because SHP projects in the United States are rated using the LEED system, the population was defined as already-completed LEED-rated buildings.

The key project participants (architect, general contractor, owner, etc.) in these projects will of necessity have the most relevant information. While the US Green Building Council provides a list of certified LEED projects, no database including participants' contact information exists. Therefore, the sample frame adopted for the selection of the sample comprised several online professional groups potentially containing LEED project participants, such as the 'LEED Accredited Professional' group on 'LinkedIn', a social networking platform for professional occupations.

The researcher prepared a cover letter including information about the research as well as a link to the survey and sent it via email to the online professional groups. Appendices C and D include the cover letter and the questionnaire survey included in the link, respectively. In order to reach a greater number of potential respondents, the researcher also recruited his professional and personal contacts into reaching other potential LEED project participants.

The next step in sampling design was determination of sample size, an important aspect of empirical research that can affect the statistical precision of the results (Dattalo, 2007). In other words, results based on larger sample sizes tend to represent the population parameters more accurately. The size of a sample needed for a study should be determined by balancing the four factors of finding accurate estimates: variability of sampling, feasibility, achievement of research objectives, and cost-efficiency (Dattalo, 2007). While there are complex mathematical formulae

for calculating the sample size needed in research, such as the one presented by Kelley & Maxwell (2003), several studies (Green, 1991; VanVoorhis & Morgan, 2007) suggest a guideline for determining regression sample sizes, based on which the needed sample size should be larger than $50+m$, where m is the number of independent variables. In the present doctoral dissertation, the maximum number of potential independent variables was 7 (6 control (contextual) variables + 1 integration assessment index variable). As a result, the needed sample size would be 57.

5.1.5. Questionnaire Deployment

As mentioned, the questionnaire was deployed by sending email, including a cover letter and the survey link, to the potential respondents. 79 responses were collected over a one and half month period. It is impossible to determine the response rate using this number because the online professional groups among whom the survey was distributed did not specify how many of their LEED Accredited Professionals have worked on LEED projects. However, the sample size of 79 in this study was considered to be valid, given the construction industry's infamous reputation for low response rates to survey questionnaires (Ankrah, 2007) and the fact that some other studies with similar scopes and the same target population, such as Korkmaz (2007), use sample sizes with lower number of cases. Moreover, this sample size is more than adequate for regression analysis purposes, based on the suggestions provided by Green (1991) and VanVoorhis and Morgan (2007).

5.2. ANALYSIS PROCEDURE

The procedure for statistical analysis of the data included data preparation, preliminary data analysis, reliability testing, and multivariate regression analysis.

5.2.1. Data Preparation

An important step before beginning any analysis of collected data is to prepare the data for use in statistical analysis software. This is achieved by recoding variables and responses, constructing new variables, examining the data for missing values (and if needed, treating them), and organizing data.

At this stage, the original variables – i.e., survey questions - were first recoded by assigning them appropriate alpha-numerical codes. Because most of the variables were categorical variables with 5-point Likert-scale responses representing various levels of agreement, the responses were coded by assigning numerical codes ranging from 1 to 5. Because the collected responses represented projects rated under different LEED versions (i.e., V1.0, V2.0, V2.2, and V3.0) and because different LEED versions have different minimum and maximum possible limits for gaining Certification, Silver, Gold, and Platinum ratings, the variables representing total LEED credits and Energy and Atmosphere (EA) LEED credits had to be normalized so that the number of credits achieved by each project represent the same level of sustainability achievement. Furthermore, three new variables were constructed using the formulae 1, 2, and 3, as explained in section 4.4 of the dissertation, to represent the Challenge Index (CI), Integration Assessment Index (IAI), and Performance Index (PI). Table 5-1 shows the type, codes, and factors associated with variables (questionnaire questions).

At this stage, the data were checked for missing values. Examining the data showed that minimum levels of missing values (a few per some variables) were contained in the data. This type of missing values, those that do not happen systematically, is called ‘missing at random’ (MAR). MAR values were replaced in the dataset by their neighboring non-missing values. Finally, the data were organized by bringing the variables of the same CIPP category next to each other in the dataset.

Table 5-1. Types and Codes of Variables and Associated Factors

Code	Evaluation category	Variable	Type	Question# in questionnaire (Appendix D)
PAR		Party represented by the respondent	Nominal Categorical	1
LOC		Location	Nominal Categorical	2
YEAR		Construction year	Continuous	3
OWN		Owner type	Nominal Categorical	4
SIZE		Project size (sf)	Continuous	5
COST		Project cost (dollar)	Continuous	6
LDVR		LEED version (1.0, 2.0, etc.)	Nominal Categorical	9
LDTCR		Total LEED credits achieved	Continuous	10
LDECR		Energy & Atmosphere credits achieved	Continuous	11
CMP	Context	Complexity and Uncertainty level	Ordinal Categorical	13
PTY	Context	Priority level	Ordinal Categorical	14
PDS	Context	Project delivery system	Ordinal Categorical	12
CONT1	Context	Integration level of contract	Ordinal Categorical	15
CONT2	Context	Sustainability inclusion in contract	Ordinal Categorical	16
CI	Context	Challenge Index	Continuous	
TEAM	Input	Team capability level	Ordinal Categorical	17
TOOL	Input	Implementation of tools and technology	Ordinal Categorical	18
COL1	Process	Collaboration > Accountability	Ordinal Categorical	19
COL2	Process	Collaboration > Commitment	Ordinal Categorical	20
COL3	Process	Collaboration > Communication 1	Ordinal Categorical	21
COL4	Process	Collaboration > Communication 2	Ordinal Categorical	22
COL5	Process	Collaboration > Compatibility	Ordinal Categorical	23
COL6	Process	Collaboration > Involvement	Ordinal Categorical	24
COL7	Process	Collaboration > Joint operations 1	Ordinal Categorical	25
COL8	Process	Collaboration > Joint operations 2	Ordinal Categorical	26
COL9	Process	Collaboration > Mutual Respect	Ordinal Categorical	27
COL10	Process	Collaboration > Trust 1	Ordinal Categorical	28
COL11	Process	Collaboration > Trust 2	Ordinal Categorical	29
LEAD	Process	Leadership	Ordinal Categorical	30
SYS1	Process	System-thinking 1	Ordinal Categorical	31
SYS2	Process	System-thinking 2	Ordinal Categorical	32
IAI	Input & Process	Integration Assessment Index	Continuous	
LDCR	Product	LEED certification level	Ordinal Categorical	7
SUSC	Product	Cost success level	Ordinal Categorical	33
SUST	Product	Schedule success level	Ordinal Categorical	34
SUSI	Product	Innovation level	Ordinal Categorical	35
SUSS	Product	Safety success level	Ordinal Categorical	36
PI	Product	Performance Index	Continuous	

5.2.2. Preliminary Data Analysis

In this section, a review of the sample characteristics, respondent profile, and some descriptive statistics are first provided. Then, the efforts made to check the reliability and validity of the items are explained. The preliminary and main data analyses for this doctoral project were calculated using Stata SE 10.0, a general-purpose statistical software package.

5.2.2.1. Sample Characteristics

The 79 responses collected were provided by various participants of LEED-rated projects. As Figure 5-1 illustrates, the parties of architect, general contractor (GC), and owner were represented by 59%, 25% and 13% of respondents. The remaining 3% represented other project parties such as sustainability consultants.

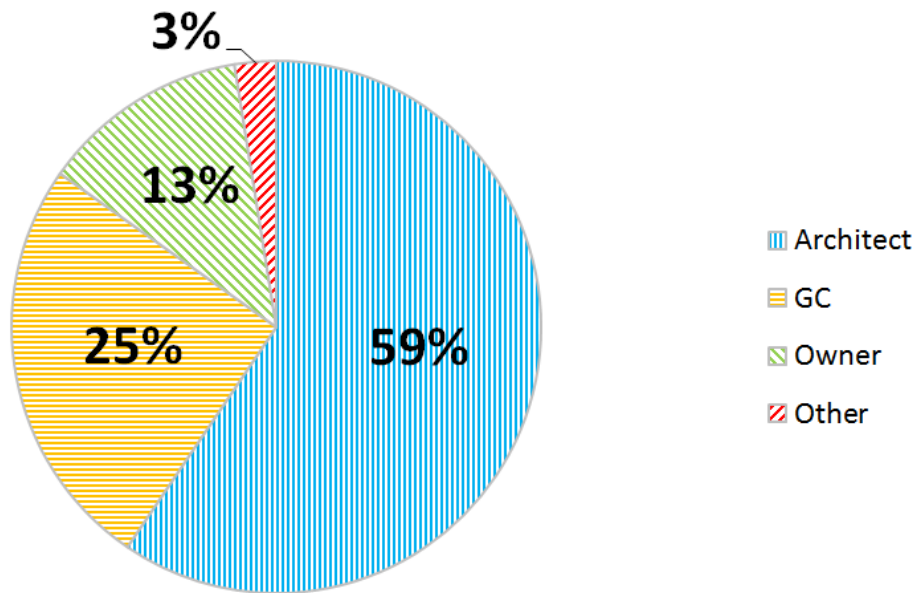


Figure 5-1. Project Parties Represented by Respondents

The respondents provided information about projects of various sizes, owner types, and locations. The projects were rated under different versions of LEED rating systems as 'Certified',

'Silver', 'Gold', and 'Platinum'. The size of projects varied between 6,208 and 1,560,000 square feet (sf). As Figure 5-2 shows, 58% of projects (N=46) were less than 50,000 square feet in size while a quarter of them (N=20) had a floor area of 50,000 to 100,000 square feet. The remaining projects (N=13) had more than 100,000 square feet of floor area.

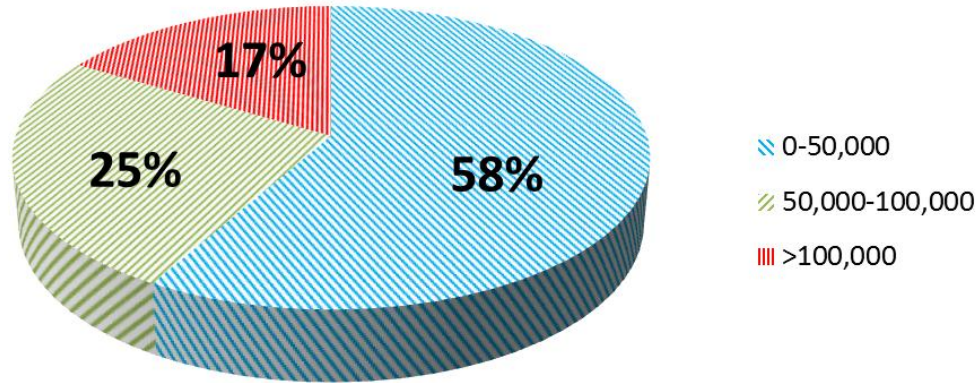


Figure 5-2. Percentage of Projects by Floor Area (Square Foot)

The questionnaire survey also captured the type of owners projects had. 78% of the projects (N=60) were privately owned and 22% (N=17) had a public client. Two projects failed to specify their owner types. Figure 5-3 illustrates the breakdown of projects by owner type.

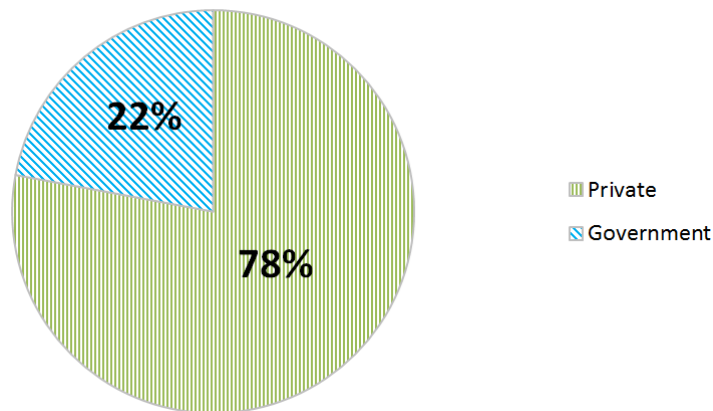


Figure 5-3. Percentage of Projects by Owner Type

As Figure 5-4 illustrates, the project delivery systems through which the projects were designed and constructed represented Design-Bid-Build (23%; N=18), Design-Build (32%; N=25) and Construction Management (45%; N=36). The type of project delivery system was captured as a contextual factor having the potential to impact the integration level of project team. These projects were rated under different versions of LEED rating system (Figure 5-5). Moreover, as Figure 5-6 shows, the level of certification varied among 'Certified' (23%; N=18), 'Silver' (22%; N=17), 'Gold' (33%; N=26) and 'Platinum' (22%; N=17).

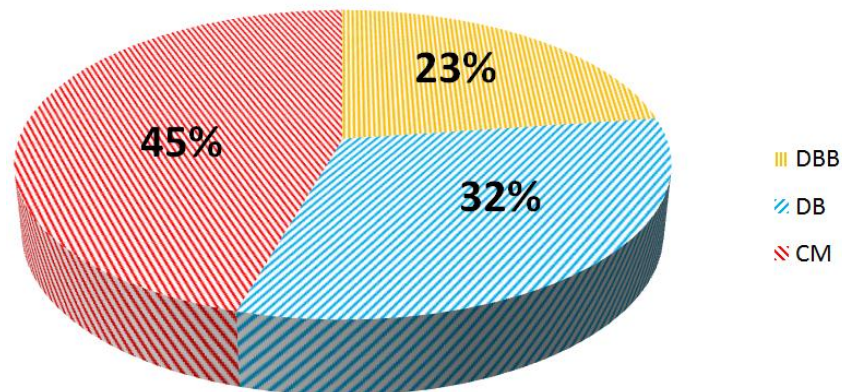


Figure 5-4. Percentage of Projects by Project Delivery System

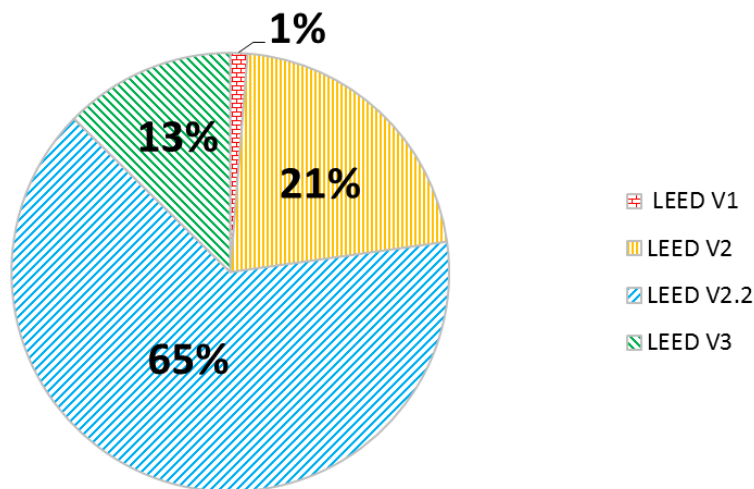


Figure 5-5. Percentage of Projects Rated by Various Versions of the LEED Rating System

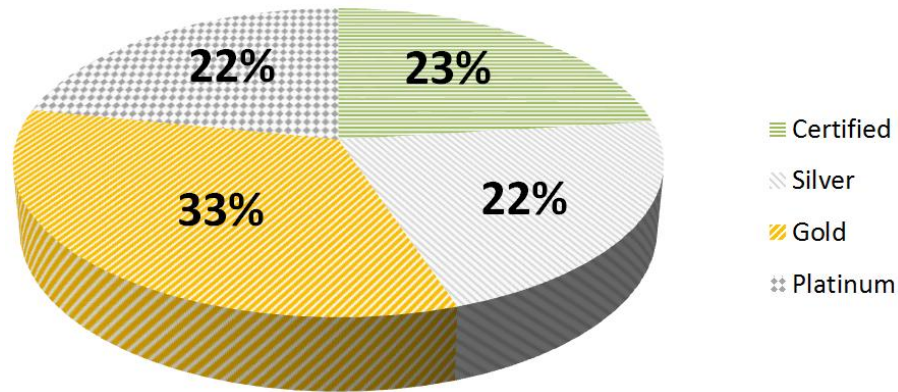


Figure 5-6. Percentage of Projects by Certification Level

5.2.2.2 Descriptive Statistics

The questionnaire also collected information on the performance of the projects under the evaluation items of the framework. It is important to remember that the questionnaire survey was designed to be a briefer version of the evaluation framework, primarily to keep the response duration within reasonable limits and thereby improve the response rate. To that end, some evaluation items were shortened in length and combined. The list of questions used in the questionnaire survey can be found in Appendix D of this report. Table 5-1 shows the codes assigned to these questions for data analysis.

Descriptive statistics for the variables in the questionnaire survey (including sample size, mean, standard deviation, minimum, and maximum) are displayed in Table 5-2.

Table 5-2. Descriptive Statistics for the Variables

	Variable	Obs	Mean	Std. Dev.	Min	Max
Challenge Index	CMP	79	3.5000	0.81204	1	5
	CPTY	79	3.7974	0.68649	2	5
	TPTY	79	3.6329	0.81927	2	5
	SPTY	79	3.8734	0.79044	2	5
	CONT1	79	3.4303	1.3076	1	5
	CONT2	79	2.9240	1.5171	1	5
	CI	79	0.5238	1.7798	-3	5
Integration Assessment Index	TOOL	79	3.4936	1.3289	1	5
	TEAM	79	3.3544	1.1986	1	5
	COL1	79	3.4050	1.3636	1	5
	COL2	79	3.4683	1.2793	1	5
	COL3	76	3.6052	1.1897	1	5
	COL4	79	3.0126	1.3252	1	5
	COL5	79	3.1139	1.3396	1	5
	COL6	76	3.4342	1.3695	1	5
	COL7	79	3.0506	1.3950	1	5
	COL8	78	3.4102	1.3429	1	5
	COL9	79	3.1645	1.3438	1	5
	COL10	79	3.2025	1.3433	1	5
	COL11	78	3.2051	1.2205	1	5
	LEAD	79	3.5949	1.2144	1	5
	SYS1	79	3.5189	1.2695	1	5
	SYS2	76	3.0526	1.4132	1	5
IAI	79	141.24	37.747	73	209	
Performance Index	SUSC	79	2.9367	.93838	1	5
	SUST	79	2.8734	.95228	1	5
	SUSI	79	3.0253	1.3202	1	5
	LDCR	78	3.0897	1.5389	1	5
	SUSS	79	4.0632	.91064	2	5
	PI	79	28.126	7.8606	12	42

5.2.3. Reliability Test Procedure

Reliability concerns the consistency of a measurement (Weiner & Greene, 2011) and the repeatability of the results (Babbie, 2010). The most widely accepted measure for reliability is internal consistency using Cronbach’s Alpha (Hinkin, 1995); internal consistency concerns “homogeneity of the items in a measure or the extent to which item responses correlate with the total test score” (Hinkin, 1995). To assess internal consistency reliability, Cronbach’s Alpha measures the degree to which evaluation items complement each other in their measurement

(Fink, 2009): the higher the internal consistency, the higher Cronbach's Alpha. This coefficient, however, is also affected by the length, i.e. the number of items in a list, and it therefore has the potential to be inflated in large item surveys, even though internal consistency may not be present (Streiner, 2003). To address this, it is suggested that Cronbach's Alpha be examined alongside other measures such as Inter-Item correlation (Streiner, 2003). There are various limits defined for the minimum acceptable level of Cronbach's Alpha, for instance 0.75 (Weiner & Greene, 2011), or 0.6 (Hair, Black, Babin, Anderson, & Tatham, 1998).

In the present research, Cronbach's Alpha was used for reliability assessment of the evaluation items in the three categories of context (Challenge Index), input and process (Integration Assessment Index), and product (Performance Index). The Alpha coefficient for the items was examined along with Inter-Item, Item-Test, and Item-Rest correlations in order to test the evaluation framework for reliability. Running the test in statistical software produces four measures below. The detailed results are presented in section 5.3.1.

- Item-Test correlation is a measure of how well each item is correlated with overall construction,
- Item-Rest correlation, or Item-Total correlation, shows how well each item is correlated with a construct that includes all items except for the one that Item-Rest correlation is reported for,
- Average Inter-Item covariance shows internal covariance of the items, and
- Alpha, or Cronbach's Alpha, shows how the alpha coefficient would change if a certain item were deleted from the list of items. The analysis also reports the Alpha for the category or construct.

5.2.4. Multiple Regression Analysis Procedure

In the next phase of data analysis, the level of achieved integration in integrated design teams' effect on achievement of project outcomes (duration, cost, sustainability, etc.), i.e. project success, was studied in order to check the framework's validity. In this phase, multiple regression analysis was applied to analyze the collected data.

In a previous chapter, the Integration Assessment Index (IAI) was introduced to aggregate the performance of a given design team with respect to its level of integration. Moreover, the success of a project in achieving a variety of outcomes was aggregated into a Performance Index (PI). The main hypothesis for this research is that the level of integration (IAI) affects the potential outcomes that the design teams can achieve. Since outcomes are also subject to factors other than team integration, a bivariate regression model which only includes PI and IAI would not yield the most accurate mathematical model to explain the changes in project outcomes. In other words, the success or failure of a project can be a result of the level of challenges it faces or its monetary resources, in addition to the integration of its project parties. Therefore, a multiple regression analysis was conducted with the inclusion of the cost variable and Challenge Index (CI), the level of integration (IAI), and PI. The addition of the cost variable and CI to this model helps isolate the effect of integration on project outcomes. In other words, by holding the level of challenges and project cost constant, it becomes possible to measure how integration alone affects project outcomes. Figure 5-7 shows the relationship between the variables.

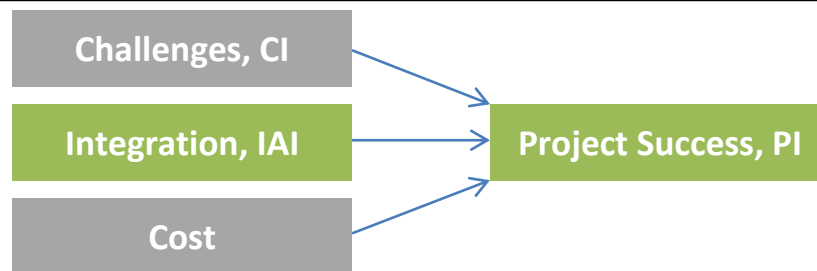


Figure 5-7. Variables in Multiple Regression Model and the Direction of their Effects

The procedure that was followed for running the multiple regression analysis is displayed in Figure 5-8.

As shown in the figure, first the data were explored visually in order to detect outliers and influential observations. Outliers are observations in a sample that deviate “markedly” from the rest of the observations in the sample (Grubbs, 1969); their presence in a model can skew the results of analysis. Influential observations are those observations having such extreme impact on the results that their inclusion in the model jeopardizes generalization of the results (Ting, 2004). In the present analysis, a scatterplot matrix of the variables in the regression model was visually examined, leading to identification of four outlier observations. These observations were excluded from the analysis.

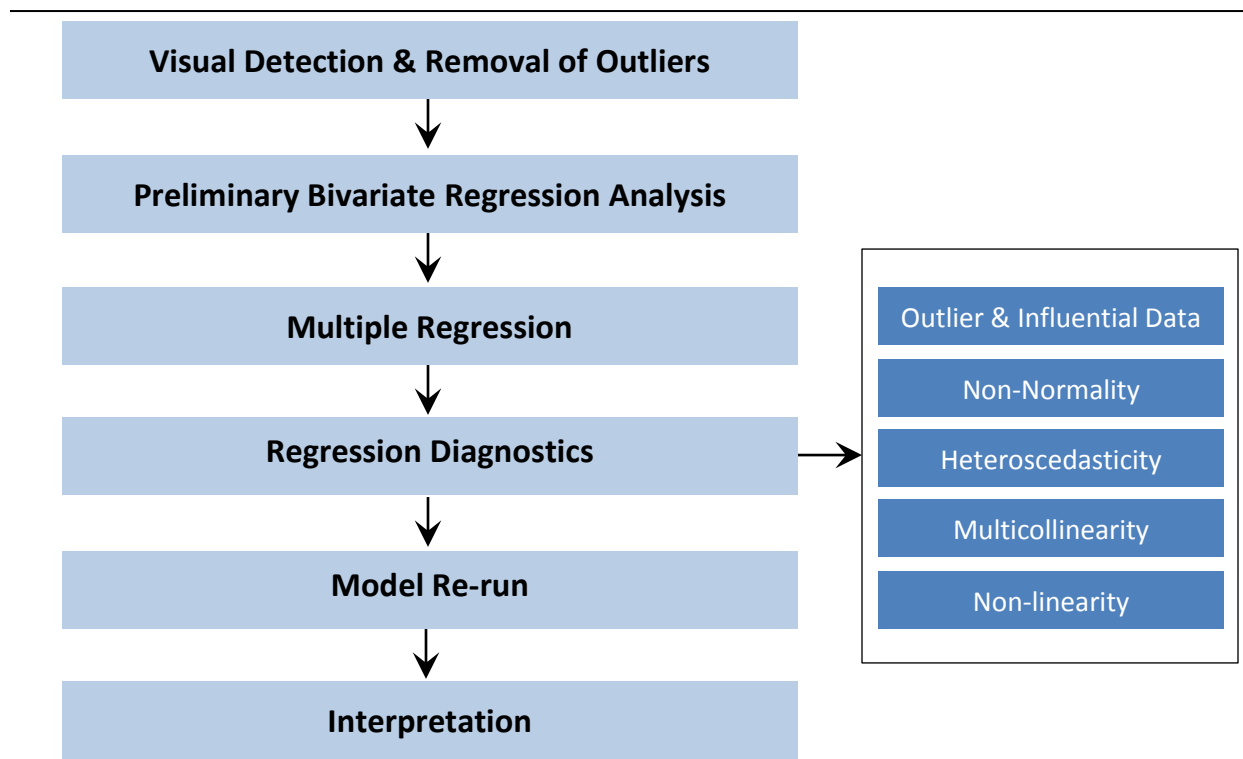


Figure 5-8. Multiple Regression Analysis Procedure

Then, a bivariate regression model including PI as dependent variable and IAI as independent variable was run in the software. The results showed a significant positive effect of IAI on PI. However, as mentioned before, cost and challenge index (CI) had to be added to the model as control variables in order to isolate the effect of IAI on PI (see Figure 5-7). Thus, a multiple regression analysis was conducted using the three independent variables. The results of the analysis showed statistically significant effects of integration (IAI) and challenge Index (CI) on project performance (PI) at the 95% confidence level, but insignificant effects of the cost variable on PI at this confidence level. Moreover, the complete multiple regression model – i.e. the model with IAI, CI, and cost as independent variables - was compared with the restricted bivariate model – i.e., the model with only IAI as an independent variable - to see whether the addition of the cost variable and challenge index, CI, to the complete model significantly improves the fit of that model. To this end, the F statistics test, a statistical test used for comparing regression models, was run to test the significance of evidence against the null hypothesis of no significant improvement of the fit in the complete model. A p-value of 0.0158 for the F-test was achieved, implying that the null hypothesis of no significant improvement could be rejected ($p < 0.05$). In other words, the addition of cost and challenge index (CI) appeared to affect the performance index at 95% confidence level.

While this model appeared relatively accurate for the purpose of this research, further analysis was needed to confirm that this is exactly what the data showed. One factor that could potentially skew the results was the presence of additional outliers/influential data. As mentioned before, four outlier observations had been detected visually prior to analysis and removed from the dataset. At this stage, two statistical measures were applied in order to detect other potential outliers and influential data: DfFit and studentized residuals. DfFit focuses on the

change in parameter estimates resulting from exclusion of an observation and is calculated using the following formula (Miles & Shevlin, 2001):

$$\text{Equation 4: } \text{DfFit} > \left| \frac{2}{\sqrt{k/N}} \right|$$

K in this equation refers to the number of predictors (independent and control variables) in the model and N represents the number of observations. Applying this equation in data analysis yielded the cutoff value of 10 for DfFit.

Studentized residuals, another measure for detecting potential outliers, examine regression residuals that have been divided by their standard deviations (Wooldridge, 2009). The recommended cutoff criterion for this measure is values greater than 2. Five observations were detected commonly by the two measures and were excluded from the analysis.

At this stage the multiple regression model was re-run using the remaining 70 observations. The results showed that removal of outliers improved the model's fit, but the cost variable remained insignificant. This model was examined for violation of regression assumptions before excluding the cost variable. Indeed, the linear regression analysis is founded on several assumptions that can be jeopardized by the following conditions (Miles & Shevlin, 2001):

- a) **Outlier and influential data** (previously addressed)

- b) **Non-linearity**, which occurs when the relationship between independent and dependent variables is not linear. This is a major concern in Ordinary Least Square (OLS)

regression models. Non-linearity was checked by visually inspecting the residual scatterplots, which revealed concerning deviation of the cost variable from linearity. To treat the problem, this variable was transformed through a natural logarithmic function. The transformed variable was labeled LGCOST (natural logarithmic function of COST). Re-analysis of the model using the transformed variable failed to increase the significance of its effect on PI. Therefore, it was dropped from the model.

- c) **Non-Normality**, which refers to non-normal distribution of residuals. To check for this threat, a numerical test called the Shapiro-Wilk W test for normality was run on the model, which resulted in a p-value of 0.2127. This indicated that there was not significant evidence against the null hypothesis of normality of residuals, at 95% confidence level ($p > 0.05$).

- d) **Multicollinearity**, which occurs when the independent variables in the model exhibit near-perfect correlation with each other. This can be detected using Variance Inflation Factor (VIF) (Baum, 2006). VIF measures the degree to which the variance inflates because an independent variable “is not orthogonal to the other regression” (Baum, 2006). VIF analysis showed that multicollinearity does not threaten this regression analysis.

- e) **Heteroscedasticity**, which refers to the lack of equal variance of the residuals for independent variables (Miles & Shevlin, 2001) and is closely associated with non-normality. The presence of heteroscedasticity can be tested using several measures such as the Breusch-Pagan and Cook-Weisberg tests (Baum, 2006). The results of running these tests in the software yielded a p-value of 0.1732 ($p > 0.05$) which indicated

that the model does not suffer from a lack of constant variance of residuals, heteroscedasticity.

- f) **Misspecification**, which happens primarily as a result of failing to include a major variable in the model, or including an irrelevant variable. To check for this problem, the Ramsey Regression Equation Specification Error Test (RESET) (Ramsey, 1969) was run in STATA; it yielded a p-value of 0.3378. This value is above the 0.05 threshold and therefore shows that misspecification is not present in the model.

The same procedure was followed for a regression analysis on two other separate models: one including total LEED credits achieved, LDTCR, as a dependent variable, and the other including energy LEED credits achieved, LDECR, as a dependent variable. It was hypothesized that 'more integrated design teams are more likely to gain greater LEED credits in Energy and Atmosphere category and also greater total LEED credits for their designed SHP project'.

5.3. RESULTS

This section presents the results of reliability assessment and multiple regression analysis to test the research hypotheses.

5.3.1. Reliability Assessment

As previously mentioned, reliability assessment was conducted using the internal consistency method. Table 5-3 displays the results of internal consistency assessment for the evaluation items in the context category. As the table shows, Cronbach's Alpha for this category is 0.6461, which is above 0.6, the minimum acceptable level suggested by Hair et al (1998). The last column in the table also reports the Alpha for each evaluation item, which is essentially the alpha level the category would have if that item were removed from it. Since the alpha levels for

all items are lower than their category's alpha level, their presence in the category contributes to the concept they represent. Moreover, examination of Inter-Item correlation and Item-Rest correlation shows acceptable levels of correlations.

Table 5-3. Internal Consistency Assessment Results for 'Context' Items

Item	Obs.	Sign	Item-Test Correlation	Item-Rest Correlation	Average Inter-Item Covariance	Alpha
CMP	75	+	0.6298	0.4168	0.4748	0.5950
PTY	75	+	0.5518	0.4272	0.5904	0.6351
CONT1	75	+	0.7716	0.4799	0.3110	0.5414
CONT2	75	+	0.8513	0.5714	0.2122	0.4753
Category					0.3971	0.6461

As mentioned before, the evaluation items in the input and process categories combine to form a single index, the Integration Assessment Index. Therefore, internal consistency assessment for the items in these two categories is performed together, as they relate to one underlying construct. Table 5-4 shows the results of internal consistency assessment for these items. Review of the table reveals that Cronbach's Alpha is well above minimum acceptable levels (0.9586). This indicates either the internal consistency of the items or their redundancy; however, redundancy cannot be the cause in this case because the correlation matrix of the items (see Appendix E) does not show high correlation of the items. Moreover, the Item-Rest correlation is within acceptable levels.

Finally, the evaluation items in the product category were checked for internal consistency. The results, as shown in Table 5-5, indicate that the evaluation items possess acceptable levels of internal consistency as judged by Cronbach's Alpha and Item-Rest correlations. There is only one item in this list whose removal can improve the alpha coefficient: SUSS, the level of a project's success in achieving safety. However, because its Inter-Item correlation was within

normal limits and its presence was meaningful based on the theory and literature in the field, this item was kept in the model.

Table 5-4. Internal Consistency Assessment Results for 'Input and Process' Items

Item	Obs.	Sign	Item-Test Correlation	Item-Rest Correlation	Average Inter-Item Covariance	Alpha
TOOL	75	+	0.7618	0.7245	1.0366	0.9564
TEAM	75	+	0.6969	0.6568	1.0616	0.9575
COL1	75	+	0.7261	0.6828	1.0407	0.9572
COL2	75	+	0.7540	0.7162	1.0408	0.9565
COL3	75	+	0.7838	0.7532	1.0435	0.9559
COL4	75	+	0.7414	0.7015	1.0416	0.9569
COL5	75	+	0.7782	0.7429	1.0317	0.9561
COL6	75	+	0.8609	0.8367	1.0096	0.9543
COL7	75	+	0.8684	0.8445	1.0049	0.9542
COL8	75	+	0.7715	0.7344	1.0308	0.9562
COL9	75	+	0.8584	0.8336	1.0119	0.9544
COL10	75	+	0.8131	0.7819	1.0231	0.9554
COL11	75	+	0.7749	0.7421	1.0428	0.9561
LEAD	75	+	0.7032	0.6617	1.0574	0.9574
SYS1	75	+	0.7839	0.7513	1.0390	0.9560
SYS2	75	+	0.8729	0.8500	1.0037	0.9540
Category					1.0366	0.9586

Table 5-5. Internal Consistency Assessment Results for 'Product' Items

Item	Obs.	Sign	Item-Test Correlation	Item-Rest Correlation	Average Inter-Item Covariance	Alpha
SUSC	75	+	0.7291	0.6013	0.6238	0.7483
SUST	75	+	0.6503	0.5005	0.6780	0.7743
SUSI	75	+	0.8494	0.7117	0.4487	0.6994
LDCR	75	+	0.9032	0.7818	0.3722	0.6787
SUSS	75	+	0.5309	0.3506	0.7544	0.8094
Category					0.5752	0.7902

5.3.2. Hypothesis 1

The central hypothesis of this research was that ‘more integrated design teams are able to achieve more successful SHP project outcomes’.

As mentioned before, Integration Assessment Index (IAI), Challenge Index (CI) and Performance Index (PI) were used as measures of integration, challenges, and project success, respectively. The results of multiple regression analysis with PI as a dependent variable, IAI as an independent variable, and CI as the control variable are shown in Table 5-6. These results are based on the final model that was examined for regression assumptions, diagnosed, and treated; therefore, they can be relied upon for testing the hypothesis. As the results indicate, the effects of integration level (IAI) and challenges (CI) on project performance (PI) are statistically significant, at the 99% confidence level ($p < 0.01$). This shows that the primary hypothesis of this research holds true.

The slope coefficient of 0.187 for IAI indicates that one scale level increase of IAI would result in a 0.187 increase in PI scale level, holding the level of challenges constant. In other words, one Likert-level increase, for instance from ‘agree’ to ‘strongly agree’, in one of the evaluation items comprising the Integration Assessment Index (IAI) - input and process categories of the proposed evaluation framework – is expected to result in a 0.187 increase in Performance Index scale level.

Table 5-6. Multiple Regression Model with PI as Dependent Variable

Number of Observations = 70		F(2,67) = 389.72			R-squared = 0.9208	
Root MSE=2.2443		Prob > F = 0.0000			Adjusted R-squared = 0.9185	
Variable	Slope Coefficients	Standard Error	T	P>t	95% Confidence Interval	
					Lower	Upper
IAI	0.1875	0.0082	22.64	0.000	0.1709	0.2040
CI	-0.4793	0.1756	-2.73	0.008	-0.8299	-0.1286
Constant	1.6820	1.2480	1.35	0.182	-0.8089	4.1730

Examining the effect of the Challenge Index on Performance Index reveals that the effect is statistically significant and negative (-0.4793; $p=0.008$). This indicates that increasing challenges in a SHP project reduces the project's success. R-squared, the coefficient of determination, for this analysis is 0.9208, which indicates that this model can explain about 92% of the change in Performance Index.

5.3.3. Hypothesis 2

The second hypothesis suggested that 'more integrated design teams are able to gain greater total LEED credits for their designed SHP project'.

The result of a multiple regression analysis with inclusion of total LEED credits (LDTCR), IAI, CI and LGCOST revealed a statistically significant effect of IAI and CI on LDTCR, each controlling for other variables, and no significant contribution of LGCOST to the model (see Appendix G.2 for details). In other words, cost changes did not seem to affect total LEED credits achieved, controlling for the level of integration and challenges. Therefore, the model was reduced to a multiple model with LDTCR as a dependent variable, and IAI and CI as independent variables.

The analysis of this model, whose results are shown in Table 5.7, confirmed the statistically significant ($P<0.01$) effect of the level of integration, IAI, on total LEED credits achieved. The IAI slope coefficient of 0.1176 indicates that one scale level increase of IAI would result in 0.1176 credit increase in LEED rating system. The R-square of 0.4063 means that about 40% of changes in total LEED credits can be explained by changes in the level of integration. The results of the multiple regression analysis confirm the second hypothesis.

Table 5-7. Multiple Regression Model with LDTCR as Dependent Variable

Number of Observations = 62		F(2,59) = 20.18			R-squared = 0.4063	
Root MSE=7.7709		Prob > F = 0.0000			Adjusted R-squared = 0.3861	
Variable	Slope Coefficients	Standard Error	T	P>t	95% Confidence Interval	
					Lower	Upper
IAI	0.1176	0.02946	3.99	0.000	.05865	0.1765
CI	-1.4554	0.6241	-2.33	0.023	-2.7044	-.2065
Constant	25.9364	4.4668	5.81	0.000	16.9982	34.8745

5.3.4. Hypothesis 3

The third hypothesis suggested that ‘more integrated design teams are able to gain greater LEED credits in the Energy and Atmosphere (EA) category for their designed SHP project’.

Similar to previous models, the multiple regression analysis of the model with LDECR as a dependent variable revealed a statistically significant effect of integration (0.07, p=0.00) on project success, controlling for the level of challenges. As Table 5-8 shows, the effect of challenges on project success was significant (-0.77, p=0.017), when controlling for integration level. Therefore, once again, the model could be run as a multiple regression model. The model could explain about 49 percent of the changes in LDECR by integration and challenge levels.

Table 5-8. Multiple Regression Model with LDECR as Dependent Variable

Number of Observations = 63		F(2,60) = 29.56			R-squared = 0.4963	
Root MSE=3.8731		Prob > F = 0.0000			Adjusted R-squared = 0.4795	
Variable	Slope Coefficients	Standard Error	T	P>t	95% Confidence Interval	
					Lower	Upper
IAI	0.0754	0.01491	5.06	0.000	.04560	.1052
CI	-0.7706	0.3131	-2.46	0.017	-1.3969	-.1443
Constant	-0.6922	2.2847	-0.30	0.763	-5.2625	3.8779

5.4. DISCUSSION

This phase of research aimed to validate the proposed evaluation framework and test three hypotheses. The hypotheses suggested that better integrated design teams are able to achieve more successful outcomes and gain greater Energy & Atmosphere (EA) and total LEED credits.

The results of the multiple linear regression analysis revealed that integration positively affects success in SHP projects, when controlling for the level of challenges. This corresponds to what the literature in the field suggests. Indeed, various literature in the field has theorized (7group & Reed, 2009; Yudelson, 2008; Kibert, 2008), or qualitatively/empirically shown (Korkmaz, 2007; Korkmaz, Swarup, & Riley, 2013), that integration level in design process positively impacts project outcomes.

In an in-depth qualitative study of 12 case-studies, Korkmaz, Swarup & Riley (2013) measured team integration level using parameters such as involvement, design charrettes, communication, compatibility, presence of LEED AP in team, prior experience, use of energy modeling, and LEED education to contractors, and examined the relationship between project delivery systems, level of integration, and achievement of the outcomes. They proposed that higher levels of integration result in more successful outcomes with respect to sustainability, cost, schedule, etc.

The negative association between the level of challenges in a SHP project and project success in the first hypotheses is not surprising, especially given that the Challenge Index (CI) in this research attempted to capture all major dimensions of challenges, including project complexity, conflicting project priorities, application of less integrated project delivery systems (such as DBB), and lack of contractual support. As one expects, success should be harder to achieve in

more challenging projects when compared with similar projects facing fewer challenges. There is no evidence of empirical research on the relationship between challenges and project outcomes, but Tatikondam and Rosenthal (2000) empirically showed that the complexity of engineering projects can be positively associated with some aspects of project performance such as schedule performance.

CII (2012) is another research that qualitatively explores the relationship between challenges, integration and project outcomes and shows that high-performing projects, compared with low-performing projects, apply higher levels of organizational integration. Also, it shows that organizational integration is improved in projects that are more challenging, compared with projects that are both less challenging and low-performing. While this may sound contradicting with the results of the present research, several limitations of CII (2012) should be noted. Firstly, CII (2012) focuses on capital projects which are inherently different from SHP projects and, therefore, its results may not be generalizable to SHP projects. Secondly, CII (2012) does not extend its research scope into a quantitative hypothesis-testing and, thus, its results need to be confirmed by empirical evidence. Thirdly, CII (2012) evaluates the level of integration and project challenges in capital projects by a few questions while the present research captures the integration and challenges with more questions and more specificity levels which improve the reliability of the results in present research. Fourthly, the results of CII (2012) do not explain why organizational integration is decreased by going from quadrant 4 to 3 (Figure 2-3) when the challenges increase. Also, the results do not explain why highest levels of organizational integration takes place in the quadrant 4 of the diagram (Figure 2-3) which represents less challenging projects. These limitations show the necessity of future research to evaluate the results in both CII (2012) and the present research.

The findings on the positive association between integration level and total and EA LEED credit gain provide empirical support to what many researchers have theorized in recent years. 7group and REED (2009), Kibert (2008), and Yudelson (2008) have all emphasized the necessity of implementing integration design to achieve fruitful outcomes in LEED projects. Indeed, more highly integrated projects are able to apply system-thinking in their design approach to a LEED project and use building performance tools to predict the sustainability and energy performance of buildings before committing to a final design. Potential feedback and analysis procedures ensure that the building has superior sustainability performance based on the defined targets.

Finally, it is worthwhile to note that the results achieved in this phase of research are not subject to the representative parties of the survey respondents. Indeed, the questionnaire survey in this research provided information on 79 different SHP projects and the survey respondents represented various project parties including architects, general contractors, owners, etc. There was a concern that whether being an architect, general contractor, or owner, could have an impact on the research results. A regression model with the inclusion of the dummy variables that captured the parties represented by the respondents revealed that these variables did not have significant effects in the model. In other words, the research results are valid across various project parties represented by the survey respondents.

5.5. IMPACTS ON INDUSTRY AND ACADEMIA

The evaluation framework developed in this research has the potential to impact the industry and academia in several dimensions. The impacts are presented below per sector impacted:

Owners

The owners of SHP projects can use the proposed evaluation framework to get familiar with various factors that affect the Integrated Design process. Moreover, the evaluation items in this proposed framework would help the owners have tangible definition of these factors so that they apply these factors in their projects and hold various project parties accountable about their implementation. The measurement format of the proposed framework facilitates the comparison of the Integrated Design process across SHP projects. Moreover, the SHP project owners can use the regression analysis results, such as the effect size of integration and challenges on project performance, to predict the potential improvement of their outcomes when certain factors in their integrated design process are manipulated. However, it should be noted that using the framework for this purpose may be more meaningful by replacing the subjective opinion-based evaluation items in the framework by more objective factual-based items.

Architects

Architects have leadership role in the design process. They can use the proposed framework to assess their SHP integrated design teams during the design process and diagnose the process for improvement purposes. Also, the framework can be used for benchmarking the performance of integrated design teams by the architects.

Other stakeholders

General contractors, consultants, and other stakeholders in SHP projects can use the proposed evaluation framework to understand the Integrated Design process and explore the evaluation factors and items applicable to their discipline. This would help them comply with the requirements for acceptable performance in the Integrated Design process.

Academia

The proposed evaluation framework can also function as a learning tool to be used in academia. It helps architecture and construction management students gain insight about various dimensions of integration in the context of SHP projects. Moreover, they can learn how to evaluate a process or project in a systematic way by exploring the organized method of evaluation embedded in the proposed framework

5.6. SUMMARY

The aim of this chapter was to describe the procedure and results of validation of the proposed evaluation framework for the Integrated Design process of SHP projects.

The validation process was based on a cross-sectional survey methodology. An anonymous online questionnaire survey was distributed to implement the proposed framework and collect information on LEED-rated projects. Utilizing the data provided by 79 responses, a quantitative reliability assessment was conducted by examining the internal consistency of the evaluation items. The quantitative measures to assess internal consistency included Cronbach's alpha coefficients, Item-Rest correlation, and Item-Test correlation; this reliability assessment revealed that the framework is internally consistent and thus reliable. Reliability is a requirement for validation.

In the next phase, the data were analyzed to examine the quantitative association between major evaluation subjects within the proposed evaluation framework, i.e. the level of challenges, integration level, and project performance. More specifically, three hypotheses were tested which suggested that more integrated design teams are able to achieve more successful project outcomes, and gain more total and EA LEED credits for their SHP design. The results of

multiple regression analyses confirmed the research hypotheses and validated the model based on reliability, construct, and internal validity measures, in addition to other aspects of validity which had been previously addressed.

6. CONCLUSION

The Integrated Design (ID) process of Sustainable High-Performance (SHP) projects is founded on the early intense collaboration of project participants and implementation of systems-thinking in their design. To ensure that Integrated Design teams reach optimum collective performance in achieving their intended objectives, the ID process should be evaluated by the owners and architects of these projects. This evaluation helps identify sources of process inefficiency to be improved, and can help avoid waste of project resources. Moreover, evaluation of the ID process provides project teams the opportunity to benchmark their performance against past and future projects.

Currently, no systematic framework exists for evaluation of the ID process of SHP projects. Therefore, the present doctoral dissertation aimed at developing and validating such a framework based on the Context, Input, Process, Product (CIPP) evaluation model. It further attempted to test hypotheses regarding the positive effect of integration level in the ID process on project outcomes.

6.1. REVISITING RESEARCH OBJECTIVES

The present research had the following four research objectives. The efforts to achieve these objectives are as follows:

1. To identify the evaluation factors/items that could be used to measure the team performance in Integrated Design process of SHP projects

Literature review and a qualitative (case-study and interviewing with industry professionals) research were applied to identify the critical factors in the ID process and provide a list of indicators, or evaluation items, to help operationalize the identified factors. 27 evaluation factors and 65 evaluation items were identified based on the CIPP model of evaluation.

2. To develop an evaluation framework for the ID process based on a systematic evaluation model

An evaluation framework was developed which consists of four components:

- a. Evaluation Model; which is based on the Context, Input, Process, and Product (CIPP) evaluation model (Stufflebeam, 2003);
- b. Evaluation Factors; which represent various dimensions of the Integrated Design process that should be evaluated;
- c. Evaluation Items; which are used for providing a reasonably tangible definition for evaluation factors in the context of the research; and
- d. Measurement Format; which provides a schema for quantifying the evaluation framework. Based on the proposed schema, three indices were defined:
 - Challenges Index (CI) to capture the level of challenges a certain project faces based on the Context category's items;
 - Integration Assessment Index (IAI) to capture the level of integration a design team achieves, based on the input and process categories' items;
 - Performance Index (PI) to measure the level of project success based on the product category's items.

Figure 6.1 illustrates the proposed framework and its components and Table 6-1 summarizes its major characteristics.

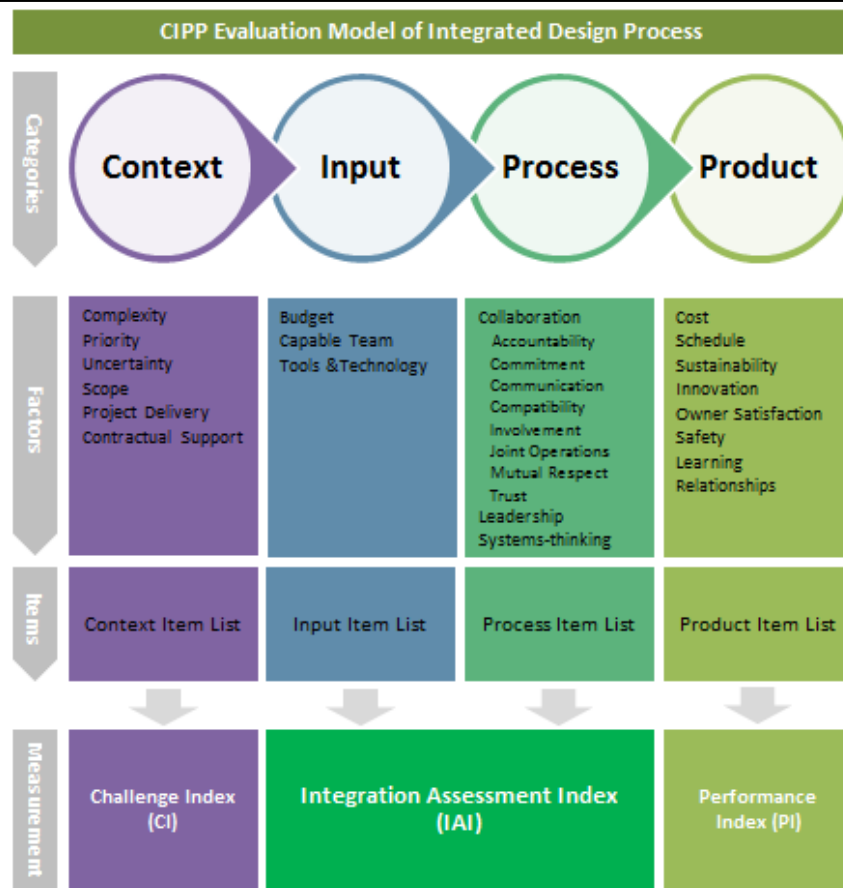


Figure 6-1. CIPP Evaluation Framework of the Integrated Design Process of SHP Projects

Table 6-1. Characteristics of the Evaluation Framework for ID Process of SHP Buildings

Evaluation subject	Integrated Design Process of SHP Buildings
Purpose	To diagnose the ID process To improve the ID process To provide an overall assessment of the IDP To guide decision-making To facilitate benchmarking
Components	a. Evaluation Model (Context, Input, Process, Product (CIPP) model) b. Evaluation Factors and Sub-factors (27; Table 4-5) c. Evaluation Items (65; Appendix A) d. Measurement Format (Challenge Index (CI), Integration Assessment Index (IAI), Performance Index (PI))
Suggested time of conduction	During the design process; Following project completion
Foci	Process-related issues; Team dynamics
Audience	Owners, architects and core project teams of SHP projects

3. To validate the proposed evaluation framework

The proposed framework for evaluation was validated through a quantitative research. To this end, a cross-sectional questionnaire survey collected data on the ID process of LEED-rated projects, resulting in 79 collected responses. The data were analyzed using statistical analysis techniques for reliability and validity assessment. STATA, SE 10.0 was the statistical software used for this purpose. For reliability assessment, the internal consistency approach was chosen, and Cronbach's Alpha, Inter-Item, and Item-Rest correlations were used as measures. Moreover, the validation process was conducted using content, construct, internal, and external validity measures. Multiple regression analysis was applied for construct and external validity, and hypothesis-testing. The results showed that framework is both reliable and valid.

4. To test the following hypotheses:

- a. 'More integrated design teams are able to achieve more successful SHP project outcomes'.
- b. 'More integrated design teams are able to gain more total LEED credits for their SHP designs'.
- c. 'More integrated design teams are able to gain more LEED credits in the Energy & Atmosphere category'.

The fourth research objective was to test the research hypotheses. Testing the hypotheses was primarily done to assess the validity of evaluation framework with respect to construct validity which examines how the association of variables (integration and performance outcomes) is in line with the existing literature suggestions. Multiple regression analysis was conducted whose results provided significant support for the research hypotheses and indicated the construct validity of the evaluation framework.

6.2. LESSONS LEARNED

The major objectives of this study were to develop and validate the evaluation framework for the ID process of SHP projects. There were, however, further lessons and findings achieved through the qualitative and quantitative phase of research which are worth reviewing. It should be noted that the lessons derived from the qualitative research are not generalizable and needs further analysis.

The lessons and findings of this study can be summarized thusly:

- **Integration and Project Outcomes**

Both the case-study research and questionnaire survey result indicate that integration has a significant effect in improving project performance in SHP projects. This association, which is net of the effect of challenges, may stem from the role of integration of project participants in creating an environment where project goals are well communicated, alignment of goals is present, information is readily and freely shared, involvement of participants occurs in a timely manner, and systems-thinking is encouraged.

The positive effect of integration on project outcomes, however, should be interpreted with caution in this study. Indeed, the level of integration in this study is captured through questions that are opinion-based. Therefore, this possibility should be taken into account that, in successful projects, respondents may inflate their assessment of integration just because they view their whole experience as positive.

- **Challenges and Project Outcomes**

The statistical analysis of the data also revealed that the challenges in a project have significant negative effect on project outcomes. The type of challenges that were captured in this study included, project complexity, project priorities, uncertainty, implementation of less integrated project delivery systems (such as DBB), project scope, and lack of contractual support. As expected, success would be harder to achieve under the conditions that these challenges are present in a project.

This finding, like previous finding, is subject to the opinion of respondents and their perception of challenges which in turn depends on respondents' experience level in industry. Also, in less successful projects, participants may have an inflated assessment of challenges which may add bias to the findings of this research with respect to the association of challenges and project outcomes.

- **Owners' Priorities and Project Success**

Project success is always defined in relation to owners' objectives and priorities. Therefore, the achievement of sustainability can be used as a measure of success in SHP construction projects, as long as it is a major goal for the owners of these projects. In this study, three major priorities (cost, time, and sustainability) were captured through the evaluation items in the framework in order to assess the owner objectives. The examination of the collected questionnaire responses indicated that sustainability was a major priority in all the cases and, therefore, the presence of sustainability as a success measure in Performance Index was valid.

- **Integrated Design and Leadership**

The industry professionals that were interviewed in qualitative phase of research highlighted the importance of leadership in the Integrated Design process. In their opinions, integrated design

teams would benefit from more mature leadership which sets the right direction for the team, motivates the members, aligns the project resources, and is capable of making decisions in a timely manner. Leaders in these teams can also properly identify the opportunities, challenges, and requirements of a project, form a capable and compatible team to respond to those, and create team environments that are engaging, positive, and fruitful.

- **Eco-charrettees and Communication**

The issue of Eco-charrettees was pointed out frequently in interviews with industry professionals. Eco-charrettees are intense workshops held at various points during schematic design which bring representatives of various disciplines together so that innovative design concepts with respect to sustainability are developed based on everyone's participation. The interviewees complained that these workshops are often little more than places for deciding and discussing which LEED credits to pursue, rather than examining innovative sustainable ideas most appropriate for a project. Therefore, if sustainability is an objective, it is important that the leaders of integrated design teams set and communicate it and use eco-charrettees as platforms for examining and discussing its various dimensions and developing innovative ideas to achieve that.

Moreover, interviewees agreed that definition and communication of sustainability, as a project objective, should take place early in the design process, and design teams should define measurable performance targets for achieving sustainability in their project so that they can assess the success of their proposed design with that respect.

- **Integration and Contract**

When asked about the importance of contracts in integration and collaboration of project parties, some interviewees believed that contractual support and the type of project delivery system

applied are both important issues but not sufficient. According to them, while contracts are important in defining the legal boundaries of team members' responsibilities, they cannot guarantee collaboration and integration of them; unless there exists willingness, commitment, respect, and trust between team members, which reinforce the contractual dimension of their relationships.

6.3. CONTRIBUTION TO KNOWLEDGE

The present study contributes to the existing knowledge in two dimensions. Firstly, it develops a systematic framework for evaluation of integration in the Integrated Design process of SHP projects. This dimension of contribution to knowledge is of special importance as previous literature (Xue, Shen, & Ren, 2010) highlights the lack of an effective framework to measure collaboration, an integration element, in construction industry. While the evaluation framework developed in this research was intended to be used for SHP projects, it can also be applied as the basis for development of frameworks to evaluation of collaboration and integration in other types of construction projects.

Secondly, the present study provides empirical support to anecdotal data suggesting integrated design facilitates the achievement of SHP projects. Literature in the field (Baiden & Price, 2011) point out the issue of limited empirical research to link integration with project performance in construction industry, therefore this study fills this knowledge gap by showing there is significant positive effect of integration on SHP project performance.

6.4. LIMITATIONS AND RECOMMENDATION FOR FUTURE RESEARCH

This study faced several limitations:

- a. There is a small population of SHP projects, and LEED projects in particular (Korkmaz, Swarup, & Riley, 2013). Finding qualitative information or collecting questionnaire-based survey responses from this population is difficult. While the sample of 79 responses collected for this project was sufficient for regression analysis, it was inadequate for more complex statistical analysis methods such as factor analysis. It is suggested that future research be conducted using larger samples, and the results re-examined.
- b. The questionnaire survey used to validate the evaluation framework was designed to be a shorter version of the framework in order to improve questionnaire response rate. While every effort was made not to compromise the survey's validity, a future study using exactly the same evaluation framework for validation purposes would be worthwhile.
- c. The questionnaire survey results in this research, like other studies allowing the survey respondents to decide whether or not to participate in the survey, are subject to the self-selection bias. As a result, there is a potential that the quantitative results in this study mostly reflect the conditions of projects with successful ID experience. Future research is suggested to adopt research design and data collection techniques that remove the self-selection bias.
- d. Many questions in the evaluation framework and the subsequent survey are opinion-based which capture the perception of LEED project participants about various issues in their design process. The differences between people's perception have the potential to bias the results. For example, unsuccessful projects might be rated as more challenging just because their project participants tend to inflate their assessment of the challenge

levels in these projects. It is suggested that future research seeks ways to found the evaluation items on more factual-based responses, rather than opinion-based ones.

- e. Since the questionnaire survey was a shorter version of the evaluation framework and some questions related to product category of the framework were not present in the survey, the Performance Index (PI) generated and used in the statistical analysis of the data is reduced, compared with the PI suggested for the evaluation framework. While major dimensions of project performance including cost, schedule, sustainability, innovation and safety were captured in the survey-based PI, it is suggested that the framework-based PI, which additionally captures dimensions such as learning, relationship satisfaction, and so forth, is used in future research and its results are compared with the results of the present study.
- f. It is beneficial to use a different sample for reliability assessment than the one used for validation and hypothesis testing (Clark & Watson, 1995). Because the construction industry is notorious for low response rates to questionnaire surveys and due to the small population of SHP projects, a similar sample was used for both purposes in the present project.
- g. This project was limited in scope to SHP projects. It is suggested that future research modify and apply the proposed evaluation framework to other types of construction projects.
- h. This project was limited in scope to the design phase. It is recommended that future research investigate the implication of using this framework during the construction phase of SHP projects.
- i. Future research can also try to expand the list of evaluation items that was generated by this research. An expanded list would allow architects and owners to evaluate their design process based on a more comprehensive list. Furthermore, larger lists will enable

future quantitative researchers to build their research based on a more complete platform.

- j. This research used Cronbach's alpha as a measure of internal consistency reliability alongside other measures including Item-Rest correlation and Inter-Item correlation. It is suggested that other measures, such as factor loadings, be also used in future research for reliability assessment and check the consistency with the results of this study.

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APPENDIX A: Evaluation Items

		Strongly Disagree (score=1)	Disagree (score=2)	Neutral (score=3)	Agree (score=4)	Strongly Agree (score=5)
Context						
Complexity	1. The project is complex with respect to providing financial resources and paying the parties for their services.					
	2. The project is complex with respect to planning and timing of the execution of activities, given the environmental context.					
	3. The project is technically complex, especially in terms of the building systems, project size, and the requirements of the project.					
Priority	4. Project cost is a major priority in this project.					
	5. Project schedule is a major priority in this project.					
	6. Project sustainability is a major priority in this project.					
Uncertainty	7. There are high levels of uncertainty surrounding this projects which posed project at high degrees of risk.					
Scope	8. The project scope is fully defined before the architect is brought on board.					
Project Delivery	9. The roles and responsibilities of project parties are assigned under project delivery systems that support integration of project participants.					
Contractual Support	10. The type and terms of the contract support the integration of project parties and their full collaboration.					
	11. Sustainability requirements and goals for the project have been integrated into the contract of the core team.					
Input						
Budget	12. There is a balance between project budget and the expected outcomes.					
Team Capability	13. The project owner is resourceful to make the needed decisions for this project timely.					
	14. The team as a whole possesses sufficient experience and expertise needed in design and construction of this project.					
Tools	15. Building performance tools are widely used in schematic design phase.					
	16. Building Information Models are widely used in design and construction phase.					

Process						
Accountability	17. The team members are held responsible by the team leadership for timely accomplishment of the assigned tasks.					
Commitment	18. Project team members show patience and willingness during the team meetings to explain issues not clear to other parties.					
	19. Project team members listen patiently and eagerly during team meetings to the issues and concerns raised by other parties.					
	20. Project team members do not get frustrated in addressing the received feedback on their work.					
Communication	21. The project goals are communicated effectively among the project team members.					
	22. The team have regular formal meeting and they can readily reach others formally or informally when needed.					
	23. The team members attend the meetings prepared.					
	24. The team members spend their meeting times critically engaging in exploring and evaluating solutions to the design problems.					
	25. The team members are able to get the needed information at the least possible time through formal means of communication (email exchange, phone calls, etc.).					
	26. There is a strict but easy-to-use protocol in place for sharing and updating the documents, drawings, models, etc. among project parties which prevented confusion and conflicts.					
Compatibility	27. The team members are familiar with each other through previous work or reputation.					
	28. The team members are compatible at both personal and organizational levels.					
Involvement	29. Project owner or its representative is actively involved throughout the design process.					
	30. In addition to architect and owner, the representatives of the following disciplines are present in the team and actively engaged in the design process: civil engineering, structural engineering, mechanical engineering, electrical engineering, lighting design, plumbing engineering, cost estimating, general contractor, major trade contractors, major suppliers, users.					
	31. The addition of representatives of the following disciplines to the team happens timely during the design process: civil engineering, structural engineering, mechanical engineering, electrical engineering, lighting design, plumbing engineering, cost estimating, general contractor, major trade contractors, major suppliers, users.					
Joint Operations	32. Consultants, subcontractors, suppliers and vendors are selected to join the team, collaboratively and based on the inputs of the core team.					
	33. The team members collaboratively set time, cost and sustainability goals.					
	34. The team members collaboratively set performance targets to meet the defined goals.					
	35. Many innovative ideas with respect to sustainability issues, form, program, value-adding, etc., are generated during the joint meetings.					
	36. The team collaboratively produces several design alternatives based on the jointly-generated ideas and revises/refines them based on their input.					
	37. Before selecting the final design, the design alternatives are					

	discussed by the team and their achievement of performance targets is evaluated.					
Mutual Respect	38. The team members are sympathetic towards other parties' situation.					
	39. Project team members go beyond their obligations in meeting other parties' requests.					
	40. The team members feel valued by other team members.					
Trust	41. The team members are confident they could receive right information from other parties at the right time without too much effort.					
	42. The team members believe in capabilities of each other and the team.					
	43. The team members are confident their voice would be heard and the project team's decisions would reflect the concerns of everyone on the team.					
	44. The team members are confident the project team's decisions would be the most beneficial for the project and for the team.					
	45. The team members are confident no one on the team will take action against the interests of others to achieve what he wants.					
	46. The team members are confident all parties will be transparent in their communication with other parties.					
	47. The team members are confident the team has made or makes sufficient efforts to examine all potential solutions to the design problem.					
Leadership	48. The owner possesses the required capability and makes sufficient efforts in setting directions and aligning team resources for the project.					
	49. The owner possesses the required capability and makes sufficient efforts in motivating the team members, fostering a sense of ownership and building trust among them.					
	50. The owner possesses capability to make fast and stable decisions based on the input of the design team.					
	51. The project architect possesses the needed capability to timely predict the design issues to be addressed, invite appropriate participants at the right time and effectively engage participants in the team discussions.					
	52. The project architect possesses the needed capability to lead the design team by communicating and pursuing the project goals and targets.					
Systems-thinking	53. The tradeoffs and synergies of the following major sustainability elements are thoroughly discussed in the joint meetings before making design decisions (form and energy use, site potentials and energy use, site potentials and daylighting, site potentials and ventilation, daylighting and energy use, ventilation and energy use, etc.)					
	54. Impacts of design decisions across relevant disciplines are discussed before making design decisions.					
	55. Impacts of design decisions over the project lifecycle are discussed before making design decisions.					
	56. The team as a whole is motivated to achieve sustainable design and followed opportunities for that through exploration and discussions rather than mere pursuit of LEED credits.					
Product (to be used following project completion)						
Cost	57. Project was successful in exceeding cost targets defined in initial					

	contract.					
Schedule	58. Project was successful in exceeding schedule targets defined in initial contract.					
Sustainability	59. Project was successful in addressing sustainability, based on LEED certification.					
	60. Project was successful in addressing sustainability comparing with other LEED-rated projects.					
Innovation	61. The project was innovative at the time of design/construction, compared with the regular practice in the market.					
Satisfaction	62. The project owner was/is satisfied with the final outcome of the project.					
Safety	63. High levels of safety compared to similar projects were achieved.					
Learning	64. Being part of this project improved the learning by project parties.					
Relationships	65. Team members were/are satisfied with the quality of relationships during design phase, and relationships survived following the completion of the project.					

APPENDIX B: Questionnaire Survey Used for Pilot Testing

Section 1: General Information

1. Which party do you represent?
 - a. Owner
 - b. Architect
 - c. General Contractor
 - d. Other (specify):

2. Project city and state:
3. Construction year:
4. Owner type:
 - a. Government
 - b. Private

5. Project size (square foot):
6. Project cost (million dollar):
7. LEED certification achieved/targeted:
 - a. Certified
 - b. Silver
 - c. Gold
 - d. Platinum

8. LEED type:
 - a. New Construction
 - b. Core & Shell
 - c. Schools
 - d. Retail
 - e. Healthcare
 - f. Commercial Interiors
 - g. Retail: Commercial Interiors
 - h. Existing Buildings
 - i. Neighborhood Development
 - j. Homes

9. LEED version
 - a. 1.0
 - b. 2.0
 - c. 2.2
 - d. 3.0

10. Total LEED credits achieved:
11. Total Energy & Atmosphere (EA) credits achieved:
12. Total Environmental Indoor Quality (IEQ) credits achieved:
13. Total Materials and Resources (MR) credits achieved:
14. Total Sustainable Sites (SS) credits achieved:
15. Total Water Efficiency (WE) credits achieved:

16. Project delivery system used:
- a. Design-Bid-Build
 - b. Design-Build
 - c. Construction Management
 - d. Integrated Project Delivery
 - e. Other

Section 2: Context

17. The project was complex with respect to providing financial resources and paying the parties for their services.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
18. The project was complex with respect to planning and timing of the execution of activities, given the environmental context.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
19. The project was technically complex, especially in terms of the building systems, project size, and the requirements of the project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
20. Project cost was a major priority in this project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
21. Project schedule was a major priority in this project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
22. Project sustainability was a major priority in this project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
23. There were high levels of uncertainty surrounding this projects which posed project at high degrees of risk.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
24. The project scope was fully defined before the architect was brought on board.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
25. The roles and responsibilities of project parties were assigned under project delivery systems that supported integration of project participants.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
26. The type and terms of the contract supported the integration of project parties and their full collaboration.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
27. Sustainability requirements and goals for the project were integrated into the contract.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

Section 3: Input

28. There was a balance between project budget and the expected outcomes.

- a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
29. The project owner was resourceful to make the needed decisions for this project timely.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
30. The team as a whole possessed sufficient experience and expertise needed in design and construction of this project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
31. Building performance tools were widely used in schematic design phase.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
32. Building Information Models were widely used in design and construction phase.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

Section 4: Process

33. The team members were held responsible by the team leadership for timely accomplishment of the assigned tasks.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
34. Project team members showed patience and willingness during the team meetings to explain issues not clear to other parties.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
35. Project team members listened patiently and eagerly during team meetings to the issues and concerns raised by other parties.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
36. Project team members did not get frustrated in addressing the received feedback on their work.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
37. The project goals were communicated effectively among the project team members.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
38. The team held regular formal meeting and they could readily reach others formally or informally when needed.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
39. The team members attended the meetings prepared.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
40. The team members spent their meeting times critically engaging in exploring and evaluating solutions to the design problems.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
41. The team members were able to get the needed information at the least possible time through formal means of communication (email exchange, phone calls, etc.).
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

42. There was a strict but easy-to-use protocol in place for sharing and updating the documents, drawings, models, etc. among project parties which prevented confusion and conflicts.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
43. BIM models were created and widely used in the project to create a shared understanding of the project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
44. The team members were familiar with each other through previous work or reputation.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
45. The team members were compatible at both personal and organizational levels.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
46. Project owner or its representative was actively involved throughout the design process.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
47. In addition to architect and owner, the representatives of the following disciplines were **present** in the team and **actively engaged** in the design process: civil engineering, structural engineering, mechanical engineering, electrical engineering, lighting design, plumbing engineering, cost estimating, general contractor, major trade contractors, major suppliers, users.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
48. The addition of representatives of the following disciplines to the team happened **timely** during the design process: civil engineering, structural engineering, mechanical engineering, electrical engineering, lighting design, plumbing engineering, cost estimating, general contractor, major trade contractors, major suppliers, users.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
49. Consultants, subcontractors, suppliers and vendors were selected to join the team, collaboratively and based on the inputs of the core team.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
50. The team members collaboratively set time, cost and sustainability goals.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
51. The team members collaboratively set performance targets to meet the defined goals.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
52. Many innovative ideas with respect to sustainability issues, form, program, value-adding, etc., were generated during the joint meetings.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
53. The team collaboratively produced several design alternatives based on the jointly-generated ideas and revises/refines them based on their input.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
54. Before selecting the final design, the design alternatives were discussed by the team and their achievement of performance targets is evaluated.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

55. The team members were sympathetic towards other parties' situation.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
56. Project team members went beyond their obligations in meeting other parties' requests.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
57. The team members felt valued by other team members.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
58. The team members were confident they could receive right information from other parties at the right time without too much effort.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
59. The team members believed in capabilities of each other and the team.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
60. The team members were confident their voice would be heard and the project team's decisions would reflect the concerns of everyone on the team.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
61. The team members were confident the project team's decisions would be the most beneficial for the project and for the team.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
62. The team members were confident no one on the team would take action against the interests of others to achieve what he wanted.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
63. The team members were confident all parties will be transparent in their communication with other parties.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
64. The team members were confident the team had made sufficient efforts to examine all potential solutions to the design problem.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
65. The owner possessed the required capability and made sufficient efforts in setting directions and aligning team resources for the project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
66. The owner possessed the required capability and made sufficient efforts in motivating the team members, fostering a sense of ownership and building trust among them.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
67. The owner possessed capability to make fast and stable decisions based on the input of the design team.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
68. The project architect possessed the needed capability to timely predict the design issues to be addressed, invite appropriate participants at the right time and effectively engage participants in the team discussions.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

69. The project architect possessed the needed capability to lead the design team by communicating and pursuing the project goals and targets.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
70. The tradeoffs and synergies of the following major sustainability elements were thoroughly discussed in the joint meetings before making design decisions (form and energy use, site potentials and energy use, site potentials and daylighting, site potentials and ventilation, daylighting and energy use, ventilation and energy use, etc.).
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
71. Impacts of design decisions across relevant disciplines were discussed before making design decisions.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
72. Impacts of design decisions over the project lifecycle were discussed before making design decisions.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
73. The team as a whole was motivated to achieve sustainable design and followed opportunities for that through exploration and discussions rather than mere pursuit of LEED credits.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

Section 5: Product

74. Project was successful in achieving cost targets defined in initial contract.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
75. Project was successful in achieving schedule targets defined in initial contract.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
76. The project was innovative at the time of design/construction, compared with the regular practice in the market.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
77. The project owner was satisfied with the final outcome of the project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
78. High levels of safety compared to similar projects were achieved.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
79. Being part of this project improved the learning by project parties.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
80. Team members were satisfied with the quality of relationships during design phase, and relationships survived following the completion of the project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

Thank you for your participation. If you have any comments or questions, please feel free to contact Rahman Azari at: razari@uw.edu

APPENDIX C: Cover Letter for Main Survey Distribution

Apologies for cross-posting

Dear LEED-AP,

If you have worked in the past on a LEED-rated project as a member of architecture team, general contractor, owner, subcontractor, engineer, etc., please take a few minutes today to answer the questions in the following **anonymous** survey which is part of my Ph.D. dissertation. Your participation in this research is voluntary and should not take more than 10-15 minutes. I appreciate your time and consideration.

Here is the link to the survey:

<https://catalyst.uw.edu/webq/survey/razari/190939>

Some information about me and my research

My name is Rahman Azari. I'm a Ph.D. Candidate in Built Environment at the University of Washington. My Ph.D. research entitled "An evaluation Framework for Integrated Design the Process of Sustainable High-Performance Buildings" attempts to a) develop an evaluation framework for performance of integrated design teams and b) validate the framework through this survey and examine the relationship between the performance of LEED project teams and their achieved outcomes. If you require any additional information about my research or this survey, please feel free to contact me at razari@uw.edu.

Researcher: Rahman Azari; razari@uw.edu

Advisor: Prof. Yong-Woo Kim, yongkim@uw.edu

Your support is highly appreciated.

Sincerely,

Rahman Azari
Ph.D. Candidate in Built Environment
College of Built Environments
University of Washington

APPENDIX D: Main (Revised) Questionnaire Survey

Section 1: General Information

1. Which party do you represent?
 - a. Owner
 - b. Architect
 - c. General Contractor
 - d. Other (specify):

2. Project city and state:
3. Construction year:
4. Owner type:
 - a. Government
 - b. Private

5. Project size (square foot):
6. Project cost (million dollar):
7. LEED certification achieved/targeted:
 - a. Certified
 - b. Silver
 - c. Gold
 - d. Platinum

8. LEED type:
 - a. New Construction
 - b. Core & Shell
 - c. Schools
 - d. Retail
 - e. Healthcare
 - f. Commercial Interiors
 - g. Retail: Commercial Interiors
 - h. Existing Buildings
 - i. Neighborhood Development
 - j. Homes

9. LEED version
 - a. 1.0
 - b. 2.0
 - c. 2.2
 - d. 3.0

10. Total LEED credits achieved:
11. Total Energy & Atmosphere (EA) credits achieved:
12. Project delivery system used:
 - a. Design-Bid-Build
 - b. Design-Build
 - c. Construction Management
 - d. Integrated Project Delivery
 - e. Other

Section 2: Context

13. The project was complex and uncertain compared with other projects I have done in the past.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
14. The following priorities important throughout the course of project:
Cost: a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
Schedule: a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
Sustainability: a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
15. The type and terms of the contract supported the collaboration of project parties.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
16. Sustainability requirements and goals for the project were integrated into the contract of the core team.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

Section 3: Input

17. The project team had sufficient resources (budget and team capability) to make the needed decisions for this project timely and accomplish the project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
18. Building performance tools and Building Information Models were widely used over the course of project.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

Section 4: Process

19. The team members were held responsible by the team leadership for timely accomplishment of the assigned tasks.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
20. Project team members showed patience and willingness during the team meetings to explain, listen to and address the issues raised during the meetings.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
21. The team held sufficient regular formal meeting and the team members attended prepared and engaged.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
22. There was a strict but easy-to-use protocol in place for sharing and updating the information.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
23. The team members were familiar with each other and compatible at both personal and organizational levels.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

24. The owner and representatives of needed design and construction disciplines were **present** and **actively engaged** from early on in the design process.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
25. The team members collaboratively set time, cost and sustainability goals and performance targets.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
26. The team collaboratively produced many innovative ideas and several design alternatives based on the jointly-generated ideas and revises/refines them based on their input.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
27. The team members were sympathetic towards other parties' situation and went beyond their obligations in meeting other parties' requests.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
28. There were high levels of trust among team members with respect to timely information, capabilities of the members, the decisions made and solutions to the design problems.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
29. There were high levels of trust among team members with respect to transparency of communications and the lack of actions against the interest of others.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
30. The owner possessed the required leadership capability in setting the directions and motivating the team and the architect possessed sufficient capability in addressing the project goals.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
31. Impacts of design decisions across relevant disciplines were discussed in joint inclusive meetings before making design decisions.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree
32. The project was designed considering its life-cycle impacts on environment.
a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

Section 5: Product

33. Project was successful in achieving cost targets defined in initial contract.
a) Strongly Disagree (10% or more cost overrun)
b) Disagree (less than 10% cost overrun)
c) Neutral (exactly on budget)
d) Agree (less than 10% under budget)
e) Strongly Agree (10% or more under budget)
34. Project was successful in achieving schedule targets defined in initial contract.
a) Strongly Disagree (10% or more schedule overrun)
b) Disagree (less than 10% schedule overrun)
c) Neutral (exactly on schedule)
d) Agree (less than 10% schedule underrun)
e) Strongly Agree (10% or more schedule underrun)

35. The project was innovative at the time of design/construction, compared with the regular practice in the market.

a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

36. High levels of safety compared to similar projects were achieved.

a) Strongly Disagree b) Disagree c) Neutral d) Agree e) Strongly Agree

Thank you for your participation. If you have any comments or questions, please feel free to contact Rahman Azari at: razari@uw.edu

APPENDIX E: Correlation Matrices of Evaluation Items

Table E-1. Correlation matrix for 'context' evaluation items

	CMP	PTY	CONT1	CONT2
CMP	1.00			
PTY	0.37	1.00		
CONT1	0.28	0.22	1.00	
CONT2	0.36	0.30	0.48	1.00

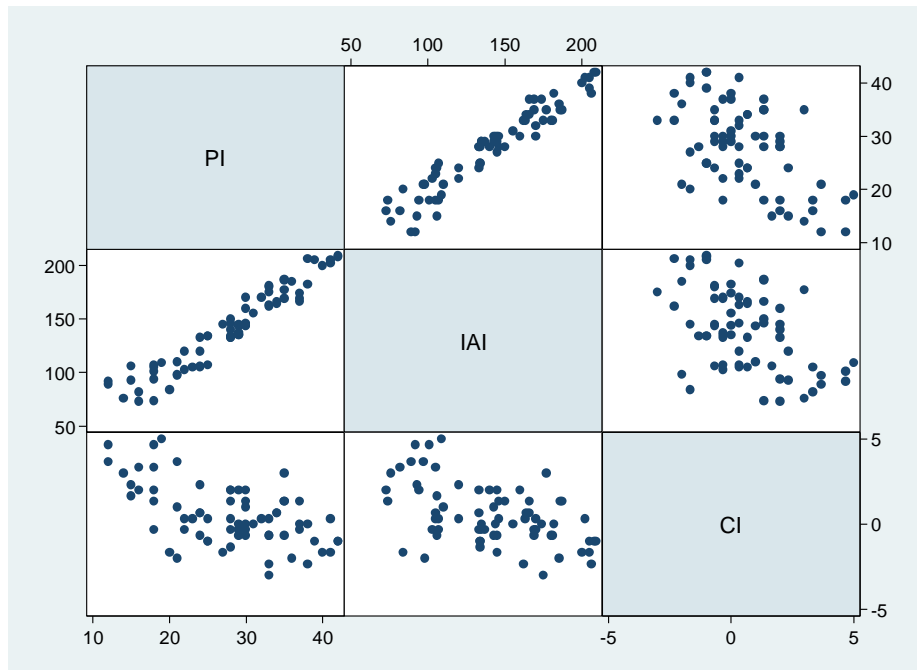
Table E-2. Correlation matrix for 'product' evaluation items

	SUSC	SUST	SUSI	LDCR	SUSS
SUSC	1.00				
SUST	0.28	1.00			
SUSI	0.53	0.41	1.00		
LDCR	0.67	0.48	0.72	1.00	
SUSS	0.18	0.32	0.32	0.28	1.00

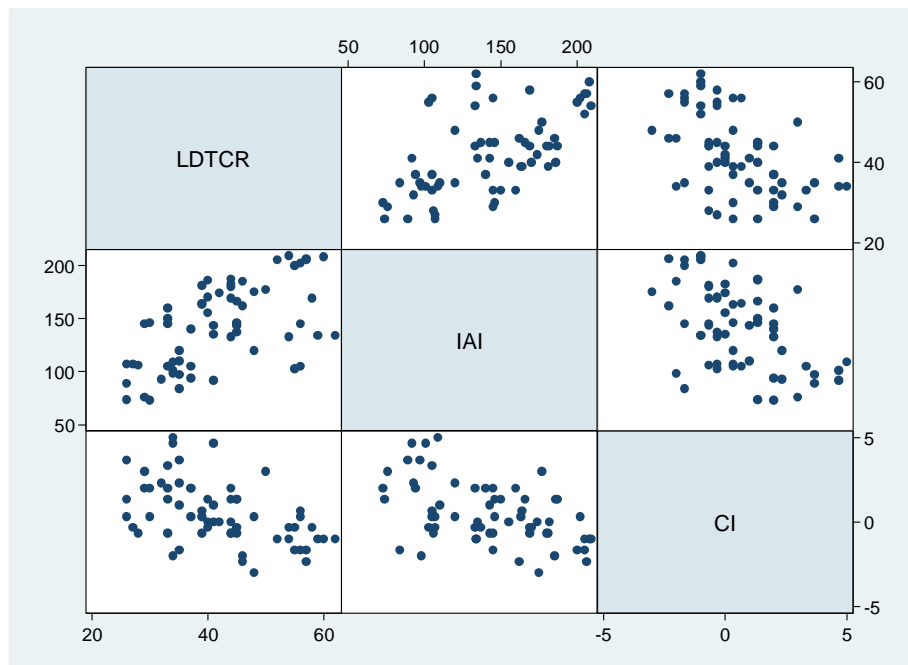
Table E-3. Correlation matrix for 'input and process' evaluation items

	TOOL	TEAM	COL1	COL2	COL3	COL4	COL5	COL6	COL7	COL8	COL9	COL10	COL11	LEAD	SYS1	SYS2
TOOL	1.00															
TEAM	0.56	1.00														
COL1	0.49	0.58	1.00													
COL2	0.55	0.53	0.60	1.00												
COL3	0.52	0.48	0.67	0.63	1.00											
COL4	0.64	0.41	0.44	0.55	0.47	1.00										
COL5	0.65	0.40	0.49	0.51	0.58	0.61	1.00									
COL6	0.60	0.66	0.55	0.62	0.58	0.62	0.60	1.00								
COL7	0.55	0.57	0.60	0.58	0.66	0.61	0.63	0.79	1.00							
COL8	0.51	0.60	0.53	0.58	0.50	0.49	0.55	0.71	0.68	1.00						
COL9	0.62	0.58	0.67	0.64	0.72	0.58	0.61	0.65	0.70	0.70	1.00					
COL10	0.56	0.44	0.52	0.51	0.60	0.55	0.66	0.66	0.75	0.54	0.68	1.00				
COL11	0.50	0.46	0.37	0.42	0.57	0.48	0.54	0.63	0.67	0.55	0.69	0.69	1.00			
LEAD	0.49	0.44	0.44	0.47	0.54	0.48	0.50	0.63	0.61	0.49	0.50	0.45	0.59	1.00		
SYS1	0.48	0.40	0.44	0.54	0.56	0.54	0.52	0.70	0.68	0.57	0.63	0.62	0.73	0.70	1.00	
SYS2	0.69	0.58	0.64	0.63	0.62	0.57	0.68	0.72	0.70	0.60	0.72	0.70	0.61	0.58	0.67	1.00

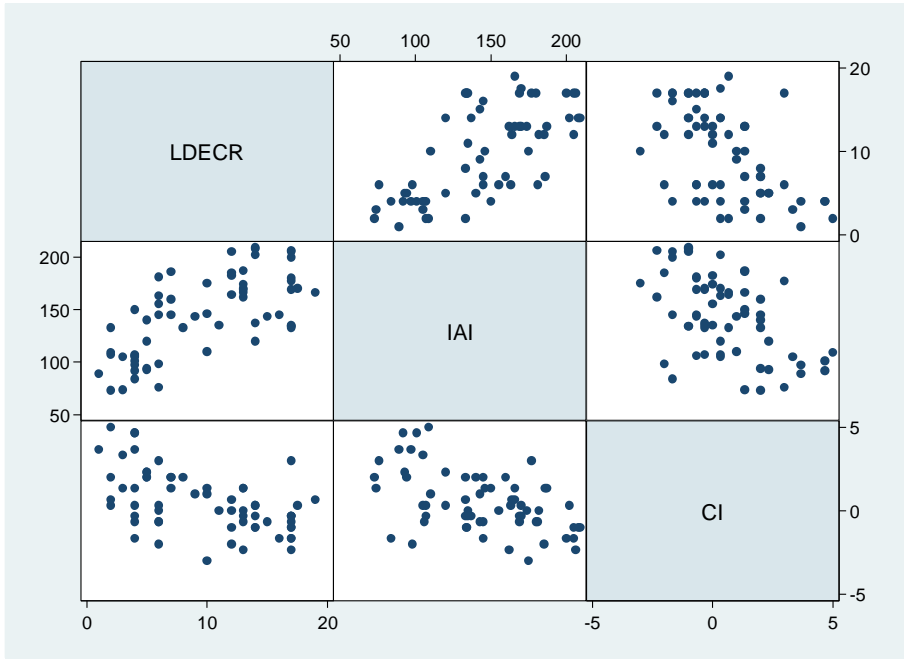
APPENDIX F: Scatterplot Matrix of Variables



PI, IAI and CI



LDTCR, IAI and CI



LDECR, IAI and CI

APPENDIX G: Regression Analysis in STATA

G.1. Hypothesis 1

```
. regress pi iai ci lgcost
```

Source	SS	df	MS			
Model	3929.82534	3	1309.94178	Number of obs =	70	
Residual	333.660377	66	5.05546025	F(3, 66) =	259.11	
				Prob > F =	0.0000	
				R-squared =	0.9217	
				Adj R-squared =	0.9182	
Total	4263.48571	69	61.789648	Root MSE =	2.2484	

pi	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
iai	.1861519	.0084426	22.05	0.000	.1692958	.2030081
ci	-.4800186	.1759973	-2.73	0.008	-.8314086	-.1286287
lgcost	.2980338	.3430884	0.87	0.388	-.3869643	.9830318
_cons	1.060579	1.440491	0.74	0.464	-1.815454	3.936613

```
. regress pi iai ci
```

Source	SS	df	MS			
Model	3926.01047	2	1963.00523	Number of obs =	70	
Residual	337.475246	67	5.03694397	F(2, 67) =	389.72	
				Prob > F =	0.0000	
				R-squared =	0.9208	
				Adj R-squared =	0.9185	
Total	4263.48571	69	61.789648	Root MSE =	2.2443	

pi	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
iai	.1875021	.0082831	22.64	0.000	.170969	.2040352
ci	-.4793211	.1756729	-2.73	0.008	-.8299656	-.1286766
_cons	1.682024	1.248001	1.35	0.182	-.8089971	4.173044

```
. hettest
```

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

H0: Constant variance

Variables: fitted values of pi

chi2(1) = 1.85

Prob > chi2 = 0.1732

```
.
```

```
. vif
```

Variable	VIF	1/VIF
ci	1.34	0.746731
iai	1.34	0.746731
Mean VIF	1.34	

```
. swilk resid
```

Variable	Shapiro-wilk w test for normal data				Prob>z
	Obs	w	V	Z	
resid	70	0.97656	1.443	0.797	0.21275

```
.
```

```
:
```

```
. ovtest
```

```
Ramsey RESET test using powers of the fitted values of pi  
Ho: model has no omitted variables  
F(3, 64) = 1.15  
Prob > F = 0.3378
```

G.2. Hypothesis 2

. regress ldtcr iai ci lgcost

Source	SS	df	MS	Number of obs =	62
Model	2555.12225	3	851.707418	F(3, 58) =	14.34
Residual	3445.47452	58	59.4047331	Prob > F =	0.0000
Total	6000.59677	61	98.3704389	R-squared =	0.4258
				Adj R-squared =	0.3961
				Root MSE =	7.7074

ldtcr	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
iai	.1251769	.0297169	4.21	0.000	.065692	.1846617
ci	-1.477138	.6192497	-2.39	0.020	-2.716701	-.2375756
lgcost	-1.750167	1.245308	-1.41	0.165	-4.242921	.7425871
_cons	29.61735	5.146687	5.75	0.000	19.31514	39.91957

. regress ldtcr iai ci

Source	SS	df	MS	Number of obs =	62
Model	2437.78749	2	1218.89375	F(2, 59) =	20.18
Residual	3562.80928	59	60.386598	Prob > F =	0.0000
Total	6000.59677	61	98.3704389	R-squared =	0.4063
				Adj R-squared =	0.3861
				Root MSE =	7.7709

ldtcr	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
iai	.1176175	.0294666	3.99	0.000	.058655	.17658
ci	-1.455481	.6241529	-2.33	0.023	-2.704408	-.2065535
_cons	25.9364	4.466874	5.81	0.000	16.99821	34.87459

G.3. Hypothesis 3

. regress ldecr iai ci lgcost

Source	SS	df	MS			
Model	893.49902	3	297.833007	Number of obs =	63	
Residual	893.413678	59	15.1426047	F(3, 59) =	19.67	
Total	1786.9127	62	28.8211726	Prob > F =	0.0000	
				R-squared =	0.5000	
				Adj R-squared =	0.4746	
				Root MSE =	3.8913	

ldecr	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
iai	.0767889	.0151251	5.08	0.000	.0465237	.1070541
ci	-.7833547	.315174	-2.49	0.016	-1.414016	-.1526929
lgcost	-.4137409	.624916	-0.66	0.511	-1.664195	.8367131
_cons	.2612788	2.709986	0.10	0.924	-5.161391	5.683948

. regress ldecr iai ci

Source	SS	df	MS			
Model	886.861372	2	443.430686	Number of obs =	63	
Residual	900.051326	60	15.0008554	F(2, 60) =	29.56	
Total	1786.9127	62	28.8211726	Prob > F =	0.0000	
				R-squared =	0.4963	
				Adj R-squared =	0.4795	
				Root MSE =	3.8731	

ldecr	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
iai	.075442	.0149173	5.06	0.000	.0456029	.1052811
ci	-.7706592	.3131143	-2.46	0.017	-1.396981	-.1443374
_cons	-.6922944	2.284795	-0.30	0.763	-5.262564	3.877975

G.4. Correlation Matrix of Variables in Regression Model

```
. pwcorr pi ldtcr ldecr iai ci, sig
```

	pi	ldtcr	ldecr	iai	ci
pi	1.0000				
ldtcr	0.4787 0.0000	1.0000			
ldecr	0.6089 0.0000	0.8533 0.0000	1.0000		
iai	0.9550 0.0000	0.4594 0.0001	0.5794 0.0000	1.0000	
ci	-0.5617 0.0000	-0.4209 0.0004	-0.5360 0.0000	-0.5033 0.0000	1.0000