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A DECISION MAKING SUPPORT MODEL TO DETERMINE APPROPRIATE CREDITS FOR GREEN BUILDING CERTIFICATION BASED ON PROJECT DELIVERY ATTRIBUTES

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ABSTRACT

Green building (GB) projects require elevated levels of interdependency and interconnectedness of different technical disciplines to respond for the needs of integrated green design systems which definitely cause higher complexities throughout the processes of GB compared to the non-green buildings (NGBs). High levels of complexity in GB processes not only create higher time and cost related waste but also other specific types of waste throughout the GB project delivery process compared to the NGBs. Prior studies identified some of the waste types and related root causes for GB projects; however, a comprehensive identification and classification of waste and related root causes still remains to be a crucial necessity for the GB industry and GB literature.

Waste generation within the GB project delivery process directly relates to the question whether the GB objectives and requirements can be fulfilled by the existing attributes of the project delivery team or not. Particularly, GB certification process embodies detailed requirements and specifications that lead to additional tasks for the project team which altogether elevate complexity levels of the whole project delivery process. In order to achieve GB certification, initially credits need to be selected among a large set of credits categorized under the GB rating system**.** Then the requirements of these selected credits and the GB rating system must be satisfied by the project and project teams. If selected GB certification credits are not suitable for the project team related GB project delivery attributes, elevated levels of time, money and labor could get wasted while attempting to fulfill the additional requirements of GB design, construction and certification.

Considering GB project attributes is critical for the analysis and optimization of GB project delivery since project attributes affect the outcomes that determine the overall success of GB projects. Hence, there is an obvious necessity for having a decision-making model to tackle with the complexities of GB projects and provide a guideline for determining appropriate GB certification credits in accordance with the project delivery attributes; however, such a model is currently absent in the GB literature.

This Ph.D. study addresses these needs by (1) by examining waste and related root causes in detail for GB project delivery process, (2) analyzing project delivery attributes that play major role in ensuring successful completion of GB projects under a hierarchical framework, and (3) developing a multi-attribute decision making support model from this hierarchical framework to determine resource efficient credits for GB certification. On the road of developing a decision making support

model, I initially identified and classified waste types and related root causes, then investigated the cause-effect relation between them by ranking them according to their negative impacts on time and cost in design and construction phases of GB project delivery process determined from a case study that includes three GB projects and performing a two-rounded Delphi Method. Drawing from my findings, I focused on two GB project delivery attributes, *i.e. timing of project teams' involvement and qualifications of project teams,* which play a crucial role for ensuring successful completion of GB projects while enduring minimal waste in GB project delivery process. Based on these two attributes, I built a hierarchical framework to assign relative weights to these attributes, and to constitute the basis of my decision making support model. Towards the achievement of my grand vision, I developed this hierarchical framework into *an integrated decision making support model*, namely *Green Building-Credit Selection (GB-CS) Model*, to determine appropriate and resource efficient (i.e. time, cost and labor) GB certification credits that suit the particular attributes of GB project delivery. *The GB-CS Model* employs the combined use of Delphi Method based weight assignment approach and TOPSIS. *The GB-CS Model* (1) designates relative weights to hierarchically designed project delivery attributes through Delphi Method based weight assignment process, and (2) determines appropriate credits in accordance with GB project delivery attributes via TOPSIS. I developed *the GB-CS Model* based on LEED® 2009 NC under BD+C Rating System. I tested and validated the *GB-CS Model* by conducting a case study on a LEED® registered residential project.

This integrated study formalizes the identification and classification of process waste with their related root causes for GB projects and reveals the cause-effect relationship between them which come together as a multi-attribute decision making support model that aid the optimization of GB project delivery and allows obtaining better outcomes from GB projects through minimizing the root causes of elevated waste and mitigating associated hidden costs. This multi-attribute model provides an interconnected decision making guideline which assesses the particular conditions of the project and project team before deciding to follow a GB rating system and determines the appropriate GB certification credits that are more likely to be obtained in an efficient and effective manner considering the particular attributes of GB project delivery. Properly selected GB certification credits would optimize GB project delivery by mitigating the excess levels of waste generated to fulfill the additional requirements of GB design, construction and certification. *The GB-CS Model* proposes to give the GB industry and literature the upper hand by facilitating GB project delivery with an adaptive guidance model that quantifies the outcomes of Green decisions and ensures the successful completion of GB projects.

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CHAPTER 1

INTRODUCTION

A "green building" (GB) or a "sustainable building" (SB) is a high performance building (HPB) that is designed and constructed to preserve energy, water, materials and land throughout its life cycle while providing healthy environments for its occupants through the application of "green" principles (Riley et al., 2004). GB projects require elevated levels of interdependency and interconnectedness of different technical disciplines (Reed and Gordon, 2000; BHKR, 2003; Korkmaz et al., 2010). Structural, mechanical, electrical and architectural systems need to function comprehensively together in a systematic unity to give birth to a project that is "Green", socially and environmentally conscious as well as energy efficient over its whole life cycle. This interconnected and interdependent nature of the GB Projects associates certain complexities with the management of the whole process (Robichaud and Anantatmula, 2011). Lack of proper design guidance in such complex situations cause mistakes to be reproduced repeatedly in every project (Korkmaz et al., 2010).

Previous research show that GB projects are generally more complex compared to the non-green buildings (NGBs) due to the collaborative and interdisciplinary nature of GB projects to respond to the needs of interconnected green design systems (Robichaud and Anantatmula, 2011). Higher complexity of GB processes not only cause higher time and cost related waste throughout the design and construction phases of GB project delivery process compared to the NGBs, but also creates some specific types of waste (Pulaski et al., 2003; Riley et al., 2004; Lapinsky et al., 2006; Horman et al., 2006). In fact, the more complex processes a project has, the more waste it can generate especially when conventional project delivery methods are used (Magent et al., 2005).

“Waste” or “process waste” is defined as non-value adding activities (NVA) that absorb resources and costs without creating any additional value for the project (Womack and Jones, 1996). Waste often leads to increased levels of hidden costs that stem from lower productivity and additional time allocated for reworks in the processes (Porter and van der Linde, 1995; Pulaski et al., 2003; Riley et al., 2004). Although previous studies identified some waste types and related root causes for GB projects, a comprehensive identification and classification of waste and related root causes is still a crucial necessity for the GB industry and GB literature.

Waste generation within the GB project delivery process directly relates to the question whether the GB objectives and requirements can be fulfilled by the existing attributes of the project delivery team or not. GB project delivery attributes are defined as variables in GB project delivery (Korkmaz et al, 2007). Specifically, GB certification process embodies detailed requirements and specifications that lead to additional tasks for the project team which altogether elevate complexity levels of the whole project delivery process.

In order to obtain GB certification, initially credits need to be selected among a large set of credits categorized under the GB rating system which necessitates the detailed assessment and evaluation of either the whole building performance or a particular building component in terms of their effects on project's planning, design, construction and operation (Adler et al., 2006; Wu and Low, 2011)**.** Then the particular requirements of these selected credits and the GB rating system (i.e. detailed documentation and advanced green system design and implementation) must be fulfilled by the project and project team. If selected GB certification credits are not suitable for the existing attributes of GB project delivery team, elevated levels of time, money and labor could get wasted while attempting to fulfill the additional requirements of GB design, construction and certification (Cassidy, 2003; Sprau, 2009; Robichaud and Anantatmula, 2011; Gultekin et al., 2013).

Considering “GB project delivery attributes” is critical for the analysis and optimization of GB project delivery since these attributes defined as the variables of project delivery affect the project outcomes that determine the overall success of GB projects (Korkmaz et al., 2007). An overall success in a project can only be achieved as the technical performance specifications and/or task requirements are met with high level of excellence that satisfy the parent organization, project teams and end users (De Wit, 1986). Achieving this high level of excellence is not an easy task since the GB processes embody certain innate complexities that need to be overcome. In order to ensure overall success for GB Projects, there is an obvious necessity for having a decision-making model that would tackle the complexities of GB projects and provide guidance for determining appropriate GB certification credits in accordance with the existing project delivery attributes; however, such a model is still currently absent in the GB literature.

This Ph.D. study addresses these needs by (1) examining waste and related root causes in detail for GB project delivery process, (2) analyzing project delivery attributes that play major role in ensuring successful completion of GB projects under a hierarchical framework, and (3) developing a multi-attribute decision making support model from this hierarchical framework to determine resource efficient credits for GB certification. This new approach considers particular GB project attributes and determines appropriate GB certification credits that can be obtained more efficiently and effectively which in return optimizes the overall GB project delivery system by minimizing the process wastes generated to fulfill additional requirements of GB design, construction and certification.

1.1 Problem Statement

Green Buildings can be described as cost effective projects due to the associated lower operational and maintenance costs throughout the life-cycle of the project in the long run (Kats et al., 2003). However, the U.S. Green Building Council (USGBC) records that the number of GB projects is still limited in the construction industry (Korkmaz et al., 2010).The total number of new construction projects certified as high performance sustainable building by the USGBC is only 10090 worldwide (USGBC, 2014a). The reason for having such a low number of GB projects is that the stakeholders (i.e. Owners) are still reluctant to invest in GB projects as they still associate GB project delivery process with elevated levels of technical difficulties that require additional cost, time and labor (Korkmaz et al., 2010; Robichaud and Anantatmula, 2011; Turner, 2012). However, the fact that these challenges that closely relate to the elevated levels of waste and reduction of productivity arise due to mismatch between the project attributes and project requirements is often overlooked (Pulaski et al., 2003; Riley et al., 2004). Particularly, inability to satisfy specific requirements of the selected GB rating system and certification credits is closely related to the mismatch between project delivery attributes and the requirements of selected credits and Owner's Project Objectives (OPR) which can be suggested to cause escalation of time, money, and labor needed for fulfilling the same work (Robichaud and Anantatmula, 2011; Wu and Low, 2010; Gultekin et al., 2013). Such mistakes in collaborative and interdisciplinary processes of GB projects lead to generation of specific wastes that result in time increases and cost overruns.

Previous studies uncovered during the literature review show that time and cost-related waste throughout GB project delivery process are much higher than that of NGBs (Pulaski et al., 2003; Riley et al., 2004; Magent et al., 2005; Lapinsky at al., 2006; Banawi, 2013; Sprau, 2009). More importantly, interdisciplinary nature of GB projects generate some specific types of waste throughout design and construction phases of GB project delivery process (Pulaski et al., 2003; Riley et al., 2004; Lapinsky at al., 2006). Most of the previous GB studies analyze major barriers for GB projects (Lam et al., 2009; Hwang and Tan, 2010; Hwang and Ng, 2013; Robichaud and Anantatmula, 2011) as they describe general obstacles in the GB processes but provide limited insight into the specific wastes associated with the GB project delivery process (Pulaski et al., 2003; Riley et al., 2004; Lapinsky at al., 2006). A comprehensive identification and classification of waste and related root causes for GB projects still remains to be a crucial necessity.

Waste types and associated root causes for GB projects need to be analyzed in detail in order to uncover the underlying reasons for prolonged durations, high cost and additional labor involved with GB projects, to mitigate the hidden costs and additional time associated with the project delivery process and most importantly to motivate owners for investment in GBs. Examination of GB project delivery process by identifying and classifying waste and related root causes helps determine the critical project delivery attributes which have considerable impact on the pursuit of GB projects. A complete analysis of GB project delivery process is necessary to address the identification of waste with related root causes and establish cause-effect relationship between them so that the connection between waste types and barriers could be manifested and the reasons for increased levels of time and expenditures could be uncovered. Such an in depth analysis facilitates the development of decision making models to help optimize GB project delivery process by overcoming the identified challenges as well as minimizing waste and related root causes; hence, decreasing associated hidden costs and time involved.

An integrated decision making model is needed to ease the negative impacts of identified challenges within the GB project delivery processes. In order to ensure the successful completion of GB projects, a decision making model is needed for providing assistance in making analytical and statistically driven management decisions that find a common ground between the composition of project delivery method and the project requirements. A model that proactively assists with determining the appropriate GB rating system and credits that are more likely to be met by the project and its project teams in an efficient and effective manner would be an invaluable tool for the GB Industry. Such an advanced guideline would ensure GB projects have successful outcomes by minimizing wastes and associated additional time, labor and hidden costs generated while fulfilling the extra requirements of GB design, construction and certification.

In the GB literature there is no study that addresses the need for having a decision making model to test the project and project team and identify which GB rating system and certification credits suit the particular attributes of GB project delivery before making such decision.

This Ph.D. research is driven by a vision that highlights the need for "an interconnected decision-making guideline" to aid the owner and/or owner's representatives in the selection of appropriate GB certification credits that can be efficiently and effectively fulfilled by the project and project teams enduring minimal waste of time, cost and labor. On the road of developing an interconnected decision making guideline, I initially identified and classified waste types and related root causes, then investigated the cause-effect relation between them by ranking them according to their negative impacts on time and cost in design and construction phases of GB project delivery process determined from a case study that includes three GB projects and performing a two-rounded Delphi Method. Drawing from my findings, I focused on two GB project delivery attributes, i.*e. timing of project teams'* *involvement and qualifications of project teams,* which play a crucial role for ensuring successful completion of GB projects while enduring minimal waste in GB project delivery process. Based on these two attributes, I built a hierarchical framework to assign relative weights to these attributes, and to constitute the basis of my decision making support model. Towards the achievement of my grand vision, I developed this hierarchical framework into an integrated decision making support model to determine appropriate and resource efficient (i.e. time, cost and labor) GB certification credits that suit the particular attributes of GB project delivery.

The next section (Section 1.2) gives an overview of the vision that my research is based on. The following section (Section 1.3) describes the research scope of this study. The subsequent sections (Section 1.4-1.5) present the objectives and methodology of my research, respectively. Finally, the last section (Section 1.6) guides the readers in my Ph.D. dissertation.

1.2 Research Vision

The vision of developing "*an interconnected decision making guideline*" has been driving the PhD research study that aims at providing help for the selection of appropriate and resource (i.e. labor, time, money) efficient GB certification credits which can be obtained in accordance with the particular attributes of GB project delivery. This envisioned guideline is for the owners/owners' representatives whose objective is to earn GB certificate for their GB project.

Within this vision, by using this integrated decision making guideline, the owner and/or owner's representative (i.e., who is the end-user) assess the existing situation of project and project team before deciding to follow a GB rating system and select the appropriate GB certification credits that are more likely to be fulfilled in an efficient and effective manner by the project and its project teams to get sufficient points for achieving the GB certification with minimal time and cost related waste. Furthermore, this guideline will enable executives (i.e. Project Manager (PM)) to build more efficient project teams according to the unique green objectives of the project and associated requirements.

Serving assistance to the owners, this advanced guideline also will help them (1) realize the negative impacts regarding the late involvement of project teams ,in GB processes and low qualifications of project teams in GB features, and (2) determine the correct time to get the team members involved in the process to accomplish the GB project delivery within the allowed time, and (3) build more efficient project teams in accordance with the Owner's Project Objectives (OPR) and the requirements of the GB project. OPR refer to the basis of all design, construction acceptance and operational decisions such as GB concepts including LEED® (Leadership in Energy & Environmental Design) certification goals (GSA, 2014). Thus, this integrated decision making guideline would allow ensuring better project outcomes in terms of time, cost and sustainability, and achieving project objectives with minimal waste.

This interconnected approach mainly employs a multi-attribute decision making support model, called ***G**reen **B**uilding-**C**redit **S**election* (*GB-CS*) *Model.* Multi-attribute decision making (MADM), a well-known branch in decision making, is developed to reflect the qualitative attributes to a framework that allows the scientific selection of numerous alternatives (Triantaphyllou, 2000).

The GB-CS Model is based on the combined use of Delphi Method and TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) in which TDR (Top-down direct rating) method is integrated as a conjunctive method. This integrated decision making support model: (1) designates relative weights to hierarchically designed GB project delivery attributes via Delphi Method based weight assignment approach, and (2) determines appropriate credits in accordance with GB project delivery attributes via TOPSIS. I developed *the GB-CS Model* based on LEED® 2009 NC (New Construction) under BD+C (Building Design and Construction) Rating System. The basic framework of the *GB-CS Model* is illustrated in Figure 1.1 by using IDEF0 modeling language which employs an input-activity-output relation.

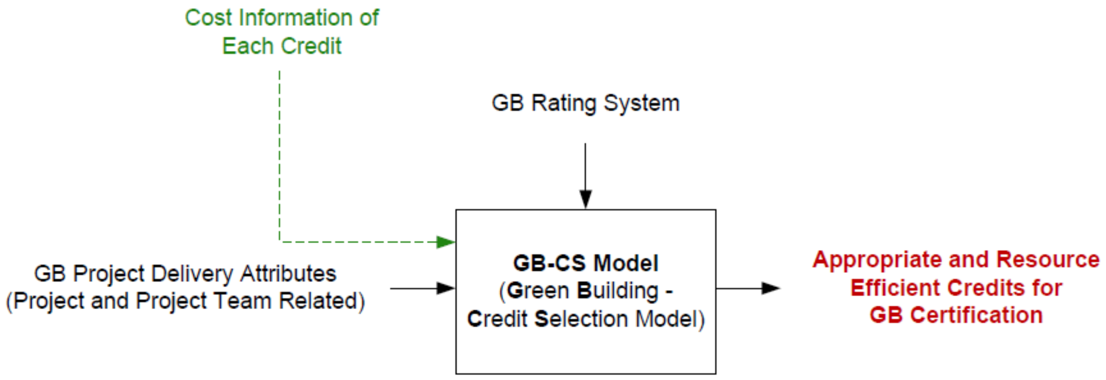

Fig 1.1: IDEF0 diagram for the Green Building-Credits Selection Model

The research vision of this interconnected decision making support model is presented in Figure 1.2.

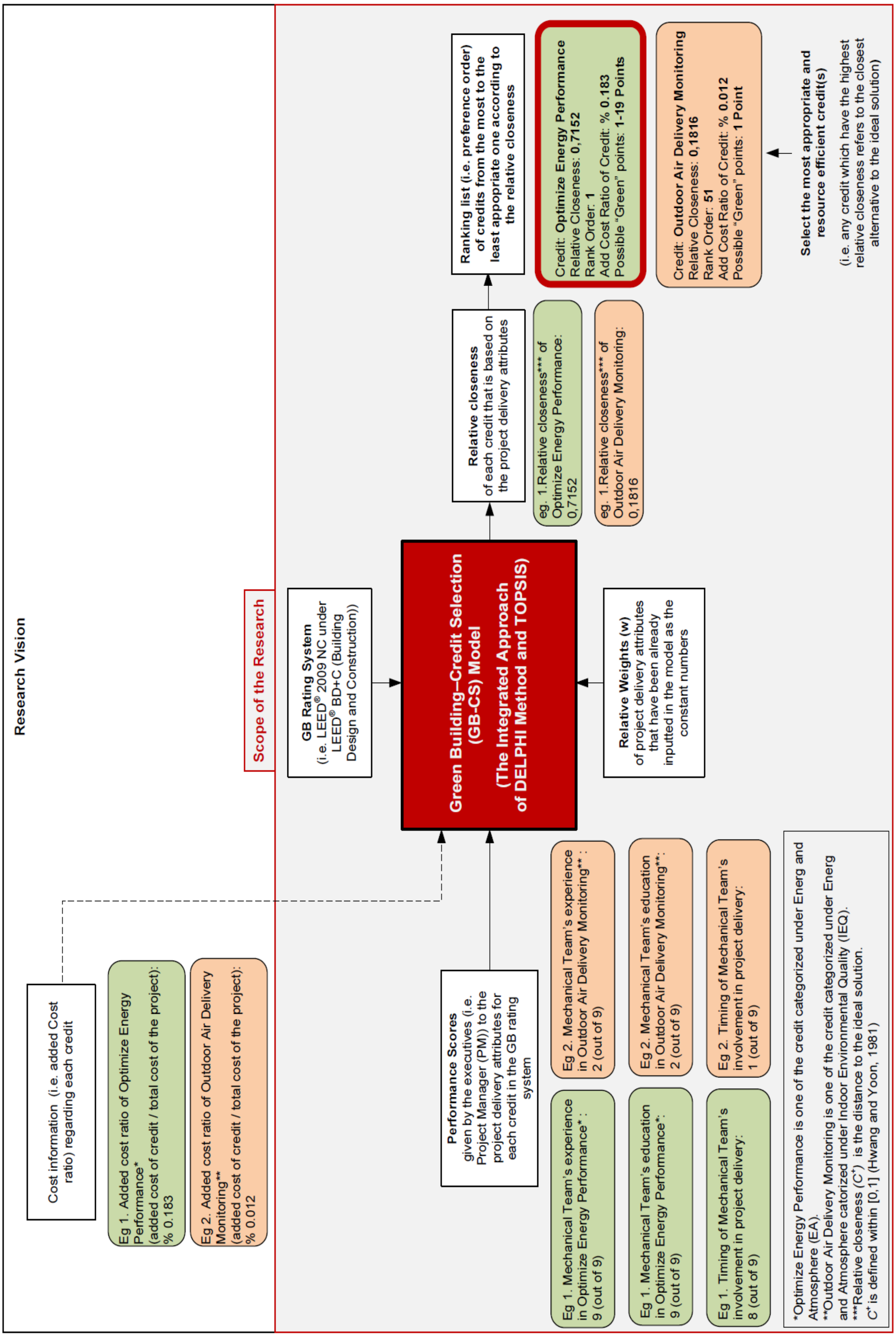

Figure 1.2: Vision of the Green Building-Credit Selection (GB-CS) Model

In this integrated approach, in order to determine appropriate credits among a large number of credits categorized under the GB rating system, *the GB-CS Model* utilizes two types of data which are as follows: (1) the relative weights of GB project delivery attributes that are inputted as the constant numbers into the model, and (2) the performance scores that are given by the executives (i.e. project manager (PM)) to the attributes for each credit and inputted into the model as the variable numbers.

Within the vision, performance scores of GB project delivery attributes will be changed from project to another; since performance scores depend on the particular attributes (i.e. qualification of project teams and timing of project teams' involvement) of the GB project delivery. The relative weights of GB project delivery attributes have been already pegged in *the GB-CS Model* before applying it on a project. In case, performance scores are inserted into *the GB-CS Model* by general contractor (GC) and/or PM and/or authorized personnel under PM as the secondary user(s). Their task is to examine the consistency between the levels of GB project delivery attributes, the intended GB rating system and the credits categorized under the GB rating system by using *the GB-CS Model*. These scores are given according to scoring systems which are specifically developed for that purpose in this study (see Table 4.1-4.3). Performance scores of each attribute given for each credit refer the average score of regarding the team. In order to provide the users (i.e. the owner, GC, PM) of *GB-CS Model* additional insight into how much financial load each of the LEED credits would introduce to the project, *"Added Cost Ratio"* (i.e. additional cost ratio regarding each credit) is integrated into the model. *"Added Cost Ratio" equals* to the ratio of *"Added Cost of a Credit"* to the *"Total Cost of the Project".*

In this vision, it is assumed that LEED ® 2009 NC categorized under LEED® BD+C Rating System is selected to be applied for certifying the project as a high performance GB project. It is also assumed that this project meets the set of minimum program requirements (MPRs) for LEED certification. MPRs consider the location, boundaries and size of the project (USGBC, 2009). When the owner target at achieving a GB certificate for his/her project according to LEED® 2009 NC Rating System, the executives (i.e. GC, PM) fill out a critical inquiry regarding *the qualification of project teams* and *timing of project teams' involvement* based on the assumptions and/or real conditions. In this approach, the project teams and qualification levels (i.e. education and experience regarding each credit in LEED® NC) of the associated team members are known by the executives. Timing of involvement of every team member is planned and budgeted for even at the early steps of project initiation by the GC. Accordingly, the executive(s) evaluate their team members separately for all different aspects (i.e. involvement, education, experience) and derive an average score for their team for each credit according to the scoring systems regarding the involvement, education and experience of every team member. These performance scores are inputted into *the GB-CS Model* as the overall score of that particular executive.

When these performance scores regarding the *qualification* (i.e. *education and experience) levels of project teams* and the *timing of project teams' involvement* are inserted into the envisioned model (see Fig. 1.1-1.2 and Fig. 4.3), the credits are ranked from the most to the least appropriate one according to the relative closeness *(*C_i^+*)* of every credit. C_i^+ is a positive coefficient attained via TOPSIS.

Within the vision of this research, any credit obtaining the highest C_i^+ correspond to the most appropriate credits, while any credit obtaining the lowest C_i^+ correspond to the least appropriate credit. Thus, the output attained from *the GB-CS Model* presents (1) relative closeness (C_i^+) for each credit, (2) ranking list of credits according to C_i^+ of credits, (3) *"Added Cost Ratio"* and (4) *"green"* points referring to each credit which are obtained from the LEED 2009® NC checklist (see Fig 4.6).

If Owner's Project Objectives (OPR) include achieving credits that *GB-CS Model* deems less suitable, the owner can choose to employ new team member(s) who is/are knowledgeable and experienced in the necessities of those GB credit(s) to avoid any obstructions along the GB design, certification, construction processes and implementation of credits' particular requirements on site. If they do not hire any additional qualified employees, the existing personnel who has limited or no experiences in the GB credits might cause technical difficulties that result in disruptions and bottlenecks throughout the GB certification process which elevate the consumption of time, money and labor more than necessary for the fulfillment of the same work.

When the new performance scores regarding the improved attributes of GB project delivery (i.e. the qualification levels of new qualified personnel) are inputted into *the GB-CS Model*, the output presents a new ranking list of credits whose C_i^+ are revised according to the improved performance scores (see Appendix B). Correspondingly, in this new ranking list the most and least appropriate credits differ from the earlier ranking list. In this manner, it is expected that, the guidance from *the GB-CS Model* provide the owners select appropriate GB certification credits that are more likely to be fulfilled in an efficient and effective manner by the project and its project teams. *The GB-CS Model*, which is expected to proactively assist the GB executives in more efficient team building and timely involvement of project teams, will allow them achieve GB certification with minimal waste by preventing the possible disruptions and bottlenecks in GB project delivery process.

1.3 Research Scope

The integrated *GB-CS Model* is advanced from the hierarchical framework which constitutes three levels (see Fig 3.2 in Chapter 3). This three tiered framework, developed in this study, is mainly divided into two attributes which are in the first level. These two primary attributes are (1) *timing of project teams' involvement in GB processes* and (2) *qualification of project teams in GB projects and features*. In the second level, there are six attributes (i.e. education, experience, feasibility (F), schematic design (SD), design development (DD), construction (CA) and in the third level seven project teams (i.e. owner, general contractor (GC), mechanical team (MT), electrical team (ET), architectural team (AT), civil team (CT), and material suppliers (MS)) list under every secondary attribute.

In this study, I designed *"timing of project teams' involvement"* part considering specifically for a Design-Build project, since Design-Build Method (DB) which is an integrated project delivery (IPD) procedure is strongly recommended to ensure the successful completion of GB projects (Korkmaz et al., 2010). In the same manner, I built "project teams" part based on the Integrated Project Team approach which is suggested as the most significant requirement for successful outcomes from GB project delivery process (Korkmaz et al., 2010; Robichaud and Anantatmula, 2011; USGBC, 2009).

In order to develop the hierarchical framework into an integrated decision making support model, I integrated credits (i.e. 54 credits) under the main categories of LEED® 2009 NC within LEED® BD+C (Building Design and Construction) Rating System into this three tiered framework as alternatives to be detected appropriate and resource efficient credits in accordance with the GB project delivery attributes for GB certification. LEED® 2009 NC consists of five main categories which are (1) sustainability sites (SS), (2) water efficiency (WE), (3) energy & atmosphere (EA), (4) materials & resources (MR), and (5) indoor environmental quality (IEQ) (USGBC, 2009). Other than these five categories, LEED® 2009 NC Rating System includes two bonus categories worth total of ten points which are (6) innovation in design and (7) regional priorities (USGBC, 2009). Among all the credits listed under LEED® 2009 NC Rating System, total of fifty four credits that correspond to 100 base points are considered within this study excluding the ten-points, since these remaining credits are defined as the bonus credits listed under "regional priorities" and "innovation in design" categories. Each credit in the rating system, that is assigned points by USGBC according to the environmental impacts and human benefits of building-related impacts that it addresses, corresponds to point(s) to be earned to achieve GB certification (USGBC, 2014b).

The level of LEED® certification depends on the number of point the project earns. LEED® Certification Program includes four levels of certifications which are Platinum, Gold, Silver, and Certified. Each level of certification has its own thresholds to be met. Corresponding thresholds for LEED® Platinum, Gold, Silver and Certified are 40, 50, 60 and 80, respectively (USGBC, 2014b).

I selected LEED® on which I built my envisioned decision making support model, since LEED® is the most accepted GB certification program (Syal et al., 2007; Gultekin et al., 2013). LEED® Certification Program, developed by U.S. Green Building Council (USGBC), includes five different rating systems that are as follows: BD+C (Building Design and Construction), ID+C (Interior Design and Construction), O+M (Building Operations and Maintenance), N+D (Neighborhood Development) and Homes. Among these rating systems, I prefer NC&MR (New Construction and Major Renovations) under BD+C Rating System, since LEED® NC under BD+C can be implemented various types of buildings. This rating system is most widely practiced GB rating systems in the United States (Haselbach, 2008; Wu and Low, 2010). Moreover, LEED® NC Rating System can be used for many types of buildings as it is particularly designed for (1) new construction projects including high rise residential buildings (i.e. 9 stories or more), offices, libraries, churches, hotels and government buildings and for (2) renovating existing buildings by improving major HVAC (heating, ventilating and air conditioning) systems, modifying significant building envelopes and rehabilitating major interiors (USGBC, 2014c).

Although LEED® v4 was issued by USGBC on 1st of January, 2014; the previous and more widely practiced LEED® 2009 is preferred for integrating into the framework. The reason for not using LEED®v4 in my PhD study is because during the time this study commenced, LEED v4 was still under development and it was not being implemented in any project. Hence, GB experts involved in the weight assignment process could not be able to properly designate the importance levels to the attributes for each credit categorized under LEED®v4 as they have no experience in this latest version of LEED®.

1.4 Research Objectives

Towards my *integrated decision-making guideline* vision, I developed three major research objectives. The objectives of this research are to:

- Identify and classify waste types and related root causes occurred in design and construction phases of GB project delivery process, and rank them based on their negative effects on time and cost in GB project delivery process to decrease the hidden costs in GB projects.
- Build the hierarchical framework based on the GB project delivery attributes, which play major role in ensuring successful completion of GB projects, and assign relative weights to these attributes to be inserted in the decision making support model.
- Develop an integrated decision making support model based on the particular attributes of GB project delivery to determine the appropriate and resource efficient (i.e. time cost and labor) GB certification credits that suit these attributes the most.

Chapter 2 of this thesis describes in detail the work done in relation to the first research objective, Chapter 3 of this thesis describes in detail the work done in relation to the second research objective, and Chapter 4 of this thesis describes in detail the work done in relation to the third research objective.

1.5 Research Methodology

My research methodology is qualitative, quantitative, exploratory, observational, descriptive, and collective (Yin, 2003, Miles and Huberman, 1994).

It is *qualitative* since it focuses on the understanding of research subject within its naturally-occurring context(s) by conducting case studies and gathering data through face-to-face interviews, direct observations, attending weekly/monthly coordination meetings, structured questionnaires used in two different Delphi Inquiries and investigation of literature. Such a case study approach engages analytical generalization in which a set of results are generalized to a broader theory, not to a larger universe (Yin 2003).

It is *quantitative* since I performed numerical and statistical analysis in the process of applying (1) two different Delphi Inquiries, (2) the Delphi Method based weight assignment approach and (3) TOPSIS.

It is *exploratory* since (1) the waste types and related root causes throughout design and construction phases of GB project delivery process were explored in a case study including three GB projects, and (2) particular attributes of GB project delivery were examined that play a major role in ensuring better outcomes from GB projects.

It is *observational* since the waste types and associated root causes were examined by participating in design coordination meetings that were performed biweekly/monthly in a high performance (HP) green hospital project. Employing such an observational research provides researchers to answer *what* phenomena occurred and *why* the phenomena occurred (Leicht et al., 2010).

It is *descriptive* since it illustrates (1) the relationship between the waste types and related root causes on an Ishikawa diagram, (2) the research vision and the research processes corresponding to each research objective on IDEF0 modeling language diagrams, and (3) the utilization of the *GB-CS Model* on a flowchart.

It is *collective* since my research methodology includes three different GB projects which are under one general contractor and located at different sites.

My PhD dissertation is a *multi-methodological* research including qualitative (i.e. literature review, case study, Delphi Method) and quantitative research methods (i.e. TOPSIS, TDR). In fact, adopting mixed methodologies ensure researchers to better realize the complex phenomena (Leicht et al., 2010). Using both qualitative and quantitative analysis in this study ensure the achievement of the research objectives in a holistic perspective. In order to point out the fundamental steps of this Ph.D. study, the whole research methodology is presented in Figure 1.3 by using IDEF0 modeling language to employ an input-activity-output relationship. In subsequent chapters (Chapter 2-3-4), the details of this integrated research methodology are described, respectively.

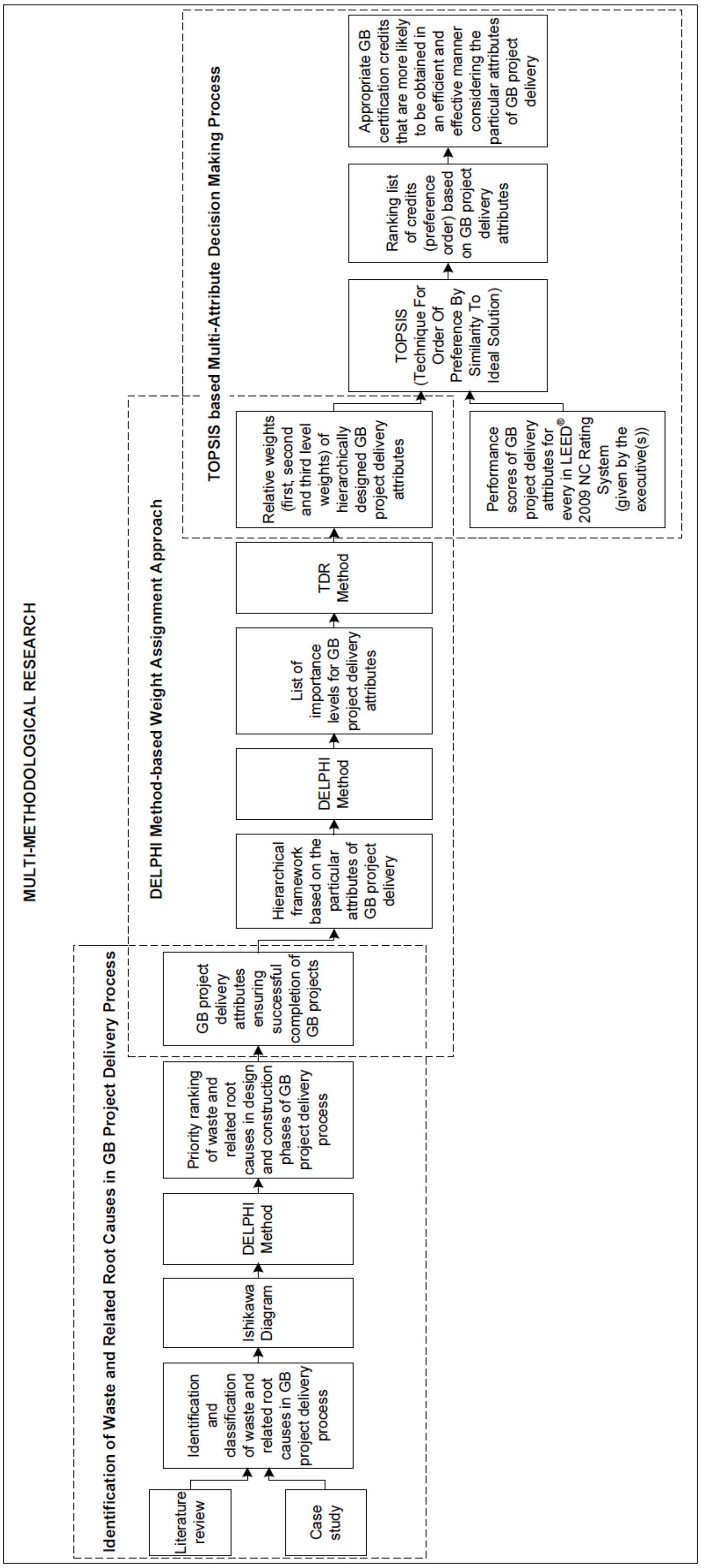

Figure 1.3: Research methodology

My research methodology has the following tasks:

1. *Reviewing the literature:* In order to provide GB industry with the upper hand and contribute to the GB literature, I made a comprehensive review of literature exploring the gaps it contains.

2. *Developing research objectives:* I developed three main research objectives to fulfill the gaps in the literature and to provide the GB industry the upper hand by facilitating GB project delivery.

3. *Conducting an exploratory case study:* In order to extend the results of the literature review and perform an in-depth analysis to identify waste and related root causes in design and construction phases of GB project delivery process, I conducted an exploratory case study on three large scale GB projects of a general contractor. I selected GB projects aimed at LEED® Gold Certificate, since this level of certificate is the most sought-after certificate level in AEC industry (Turner, 2012). The precondition for GB projects and teams to achieve a LEED® Gold Certificate is the fulfillment of at least 60%-70% of the credits in the rating system according to the general requirements of LEED® Certification Program. For this reason, project teams in my case studies focused on many of the credits in LEED® NC under BD+C Rating System. However, each credit requires additional tasks to be performed to fulfill that particular credit. Thus, working on more GB certification credits make these projects and their project delivery processes more convoluted. Complexity in the projects and processes within my case study helps me explore more types of waste and root causes for GB projects, because the more complex processes a project has, the more waste the GB project delivery process can generate (Magent et al., 2005).

4. *Building the Ishikawa Diagram:* I triangulated the findings of literature review and case study to identify and classify the waste types and related root causes. Triangulation results were illustrated on an Ishikawa diagram to represent the cause-effect relationship between waste and primary root causes including secondary root causes. Ishikawa Diagram or Fishbone Diagram is a categorical brainstorming graphic tool employed for detecting the root causes

of hypothesis and the potential causes of specific effects (Munro et al., 2008). In this manner, Ishikawa Diagram allows project teams to focus on the problem itself and on the underlying reasons of that specific problem (Banawi, 2013).

5. *Performing a Delphi Method:* I conducted a two-rounded Delphi Method on a panel of twelve experts, who are qualified in GBs and accredited by various areas of expertise, to rank the identified waste types and associated root causes based on their negative effects on time and cost in design and construction phases of GB project delivery process. Delphi Method is as a problem oriented mapping method that provides quantitative outputs (i.e. rational judgments) from a preselected group of experts through iterative rounds (Dalkey, 1972). I formalized the data collected from twelve experts in each round of the two-rounded Delphi Process.

6. *Identifying needs for ensuring successful completion of GB projects*: Drawing from my findings of previous steps, I identified the requirements for delivering a GB project with minimal waste of time, cost and labor. With the intention to meet these needs, I envisioned a multi-attribute decision making support model based on GB project delivery attributes to facilitate GB project delivery and provide aid in ensuring successful completion of GB projects.

7. *Identifying the particular attributes of GB project delivery:* In order to identify the essential attributes on which I built my envisioned decision making support model, I benefited from my findings of two-rounded Delphi Inquiry performed in the previous step. I conducted a broad literature review to corroborate my findings. Based on my findings, I focused on two GB project delivery attributes which have considerable effect on the outcomes of GB projects and would prevent the project from incurring increased waste.

8. *Constituting the reasoning mechanism of the decision making support model: A*ccording to the requirements of multi-attribute modeling, I constituted the reasoning mechanism of my envisaged decision making support model whose main purpose is to determine the GB certification credits that suit the particular attributes of GB project delivery the most. With this aim in mind, I first selected the multi-attribute decision making (MADM) method which ensures that the chosen MADM method properly detects the credits among a large number of credits. Based on the reasoning mechanism and requirements of multi-attribute modeling and the MADM method selected, the methodology performed to achieve the envisioned decision making support model was built. An in-depth literature review was firstly employed to investigate existing multi-attribute (i.e. multi-criteria) decision making (MADM) methods and to select the method which is the most suitable for the intended purpose of my envisioned decision making support model. In this study, the fundamental criterion in selection of the MADM method is having the capability for detecting the best alternative(s) among a large number of alternatives. For the purpose of my envisioned model, I selected TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) as the MADM method, since TOPSIS guarantees researchers to detect the best alternative(s) among many (Triantaphyllou, 2000). TOPSIS provides researchers select the closest alternatives to the ideal solution (Hwang and Yoon,1981).

9. *Building the hierarchical framework:* The reasoning mechanism of multi-attribute making analysis is based on reflecting the qualitative attributes to a framework that allows the scientific selection of numerous alternatives (Triantaphyllou, 2000). With regard to the reasoning mechanism and requirements of multi-attribute modeling and TOPSIS, I set a hierarchical framework, based on two GB project delivery attributes. I integrated fifty four credit categorized under LEED® 2009 NC Rating System into this three tiered framework to constitute the basis of my envisioned decision making support model.

10. *Developing the weight assignment approach:* A crucial step in the multi-attribute analysis is the weight assignment procedures and related research methods used for determining reliable values to represent the relative importance of DMs' preferences. In the multi-attribute modeling, more sensitive outputs are gathered from the weight assignment process, and more accurate results are obtained from MCDM analysis, which is used for selecting the more appropriate GB credits to be met by GB project delivery attributes.

For this reason, weights should be determined with high sensitivity and reliability (Nijkamp et al., 1990; Weber and Borcherding, 1993). According to this fundamental criterion, I developed a weight assignment approach based on Delphi Method to designate reliable and sensitive relative weights to the hierarchically designed attributes that can be used as inputs in TOPSIS. For this weight assignment strategy, I combined Delphi Method with TDR Method. In this approach, I employed Delphi Method as the main research method, since it provides increased data quality for researchers by combining several experts' judgments, and eliminating ambiguities and inconsistencies (Gunhan and Arditi, 2005). I employed Delphi Method for appointing importance levels to GB project delivery attributes via expert opinion. In this Delphi Inquiry, I used the hierarchical framework in which fifty four credit categorized under LEED® 2009 NC Rating System were integrated. In this weight assignment approach, I utilized TDR as a conjunctive method to designate relative weights of these attributes by normalizing vast amount data (i.e. importance levels) gathered through Delphi Process. Normalization makes researchers assign relative weights, whose sum should be equal to one to be inputted in a MADM method (i.e. TOPSIS). By this way, the first part of the decision making support model engaging Delphi Method based weight assignment approach provides reliable and sensitive relative weights that can be inputted in TOPSIS in the next step of my study.

11. *Employing the multi-attribute decision making method:* The second part of the decision making support model employs TOPSIS which is combined with Delphi Method based weight assignment approach. In this multi-methodological model, TOPSIS utilizes the relative weights as inputs that were attained by Delphi Method based weight assignment approach. In the integrated decision making support model, the aim of TOPSIS is to determine appropriate and resource efficient (i.e. time, cost and labor) GB certification credits in congruence with the particular attributes of GB project delivery.

12. *Testing on a LEED® registered GB project:* I tested and validated my decision making support model by conducting a case study on a residential GB project registered for LEED® Certification Program to USGBC.

1.6 Readers' Guide to the Dissertation

The Introduction and Conclusion chapters of this dissertation provide an overview of the research and describe the overall problem domain, the vision, the scope and the research objectives, and contributions and future research directions respectively. The three chapters in between the introduction and conclusion chapters describe in detail the three research objectives, the related research methodologies and the corresponding findings and contributions. Each chapter of this thesis is being submitted for publication as separate journal articles. In order to prevent repetition and provide a flow between the chapters, introduction sections of each manuscript were shortened and summarized in the Problem Statement section of the Introduction chapter.

Description of each chapter is given below:

Chapter 2 conducts a case study including three GB projects and a two-rounded Delphi Method to extend the results of the literature review and to perform an in-depth analysis for (1) identifying, and (2) classifying the waste types and related root causes, and (3) ranking them according to their negative impacts on time and cost in design and construction phases of GB project delivery process. This chapter also presents an Ishikawa diagram, which illustrates the cause-effect relationship between waste types and primary root causes consisting of secondary root causes.

Chapter 3 presents (1) a hierarchical framework based on the particular attributes of GB project delivery, and (2) the first part of my envisioned decision making support model. The first part of *the GB-CS Model* employs the Delphi Method based weight assignment approach to assign relative weights to the hierarchically designed GB project delivery attributes. These relative weights are used as inputs in the second part of this decision making support model.

Chapter 4 presents (1) the second part of my envisioned decision making support model that employs TOPSIS to determine appropriate credits and resource efficient GB certification credits that suit the particular attributes of GB project delivery the most. This chapter explains (2) the application and (3) test and validation steps of my multi-methodological decision making support model, and provides (4) a flowchart illustrating how this integrated model would be utilized as guideline in selecting appropriate credits for GB certification and in assessing the existing situation of project and project team before deciding to follow a GB Rating System.

Chapter 5, the Conclusion chapter, summarizes the results of this research study, and explains how they were validated. This final chapter also includes contributions and suggestions for further studies.

References cited in this chapter:

Adler, A., Armstrong, J.E., Fuller, S.K., Kalin, M., Karollides, A., Macaluso, J. and Walker, H. A (2006). *Green building: Project planning and cost estimating*, 2nd Ed., R.S. Means,Kingston, Mass.

Banawi, A.A. (2013) "Improving Construction Processes by Integrating Lean, Green, and Six-Sigma" PhD Dissertation. Department of Civil and Environmental Engineering. University of Pittsburgh.

BHKR (2003)."Achieving architectural and engineering collaboration in building design." *White paper*, Burt Hill Kosar Rittelmann Associates, Butler, Pa.

Cassidy, R., ed. (2003). "White paper on sustainability: a report on the green building movement" *Building Design & Construction.*

Dalkey, N.C., Rourke, D.L. and Snyder, D. (1972). *Studies in the quality of life,* Lexington Books, Lexington, Mass.

De Wit, A. (1986). "Measuring project success: An illusion." *Proc., 18th Annual Seminar/Symposium*, Project Management Institute, Montreal, Canada, 13-21.

GSA (2014). U.S. General Services Administration. <http://gsa.gov/portal/category/21600>, (Last accessed Feb. 25, 2015).

Gultekin, P., Mollaoglu-Korkmaz, S., Riley, D., and Leicht, R. (2013). "Process Indicators to Track Effectiveness of High-Performance Green Building Projects." *J. Constr. Eng. Manage.*, 139(12).

Gunhan, S. and Arditi, D. (2005). "Factors affecting international construction." *J. Constr. Eng. Manage.*, 131(3), 273-282.

Haselbach, L. (2008). *The engineering guide to LEED-New construction: Sustainable construction for engineers*, McGraw-Hill, New York.

Horman, M. J.,Riley, D. R., Lapinsky, A. R., Korkmaz, S., Pulaski, M. H., Magent, C. S., Luo, Y., Harding, N. and Dahl, P. K. (2006). "Delivering green buildings: process improvements for sustainable construction." *J. of Green Building,* 1(1), 123-140.

Hwang, B.G. and Ng, W.J. (2013)."Project management knowledge and skills for green construction: Overcoming barriers." *Int . J. of Project Manage.*, 31(2), 272-284.

Hwang, B.G. and Tan, J.S. (2010). “Green Building Project Management: Obstacles and Solutions for sustainable development,” Sustainable Development, 20(5), 335-349.

Hwang, C. L and Yoon, K. (1981). *Multiple Attribute Decision Making: Methods and Applications*. New York: Springer-Verlag.

Kats, G., Alevantis, L. Berman, A., Mills, E. and Perlman, J. (2003). “The costs and financial benefits of Green Buildings.” *Rep. Prepared for California's Sustainable Building Task Force*, Sacramento, CA.

Korkmaz S., Riley, D., and Horman, M. (2007). “Effective indictors for high performance green building delivery.” *Proc., ASCE-CIB Proc. Of the 2007 Construction Research Congress*, ASCE, Reston,Va.

Korkmaz, S., Riley, D. and Horman, M. (2010). “Piloting evaluation metrics for sustainable high-performance building project delivery*.” J. Constr. Eng. Manage.*, 136(8), 877-885.

Lam, P. T. I., Chan, E. H. W., Chau, C. K., Poon, C. S. and Chun, K. P. (2009).”Integrating green specifications in construction and overcoming barriers in their use.” *J.Prof. Issues Eng. Educ. Pract.*, 135(4), 142-152.

Lapinsky, A. R., Horman, M.J. and Riley D.R. (2006). “Lean processes for sustainable project delivery*.” J. Constr. Eng. Manage,* 132(10), 1083-1091.

Leicht, R.M., Hunter, S.T., Saluja,C. and Messner, J.I. (2010). “Implementing observational research methods to study team performance in construction management.” *J. Const. Eng. Manage.*, 136(1), 76-86.

Magent, C., Riley, D. and Horman, M. (2005). “High performance building design process model.” *ASCE Construction Research Congress*, April 5-7, San Diego, CA, 424-428.

Miles, M.B. and Huberman, A.M. (1994), *Qualitative Data Analysis: An Expanded Sourcebook*, 2nd ed., Sage Publications, Thousand Oaks.

Munro, R. A., Maio M. J., Nawaz, M. B. Ramu, G. and Zrymiak, D. J. (2008). *The certified six sigma green belt.* India, Dorling Kindersley Publishing Inc.

Nijkamp, P., Rietvelt, P. and Voogd, H. (1990). *Multi-criteria evaluation in physical planning' Amsterdam: North-Holland*. Elsevier Science Publishers B.V., Amsterdam, The Netherlands.

Porter, M. and van der Linde, *C.* (1995).*Green and competitive*. Harvard Business Review, 119-134.

Pulaski, M.,Pohlman, T.,Horman, M. and Riley, D.R.(2003). "Synergies between sustainable design and constructability at the Pentagon." *Proc.of ASCE CRC,* 1-8.

Reed, W. and Gordon, E. (2000). "Integrated design and building process: Needed research and methodologies." *Build. Res. Inf.,* 28/(5/6), 325-337.

Riley, D., Magent, M. and Horman, M. (2004). "Sustainable metrics: a design process model for high performance buildings." *Proc. CIB World Building Congress* Toronto, CA.

Robichaud, L.B. and Anantatmula, V. (2011). "Greening project management practices for sustainable construction". *J. of Manage. Eng.,* 27(1), 48-57.

Sprau, T. (2009) "Developing the Basis for Process Metrics for Sustainable Building Performance". M.S. Thesis. Department of Architectural Engineering. The Pennsylvania State University.

Syal, M.G., Mago, S. and Moody, D. (2007). "Impact of LEED-NC credits on contractors." *J. Archit. Eng.,* 13(4), 174-179.

Triantaphyllou, E. (2000), *Multi-Criteria Decision Making Methods: A Comparative Study,* Kluwer Academic Publishers, The Netherlands.

Turner Construction Company (2012). "Green building market barometer." <http://www.turnerconstruction.com/about-us/sustainability/green-market-barometer> (accessed Ap. 21, 2014).

USGBC (2009). U.S. Green Building Council. "LEED 2009 for New Construction and Major Renovations Rating System." <http://www.usgbc.org/resources/list/study-guides >, (accessed Feb.10,2014).

USGBC (2014a). U.S. Green Building Council. <http://www.usgbc.org/projects/new-construction>, (accessed Dec. 10, 2014).

USGBC (2014b). U.S. Green Building Council. <http://www.usgbc.org/articles/about-leed> , (published Oct. 17, 2014).

USGBC (2014c). U.S. Green Building Council. <http://www.usgbc.org/discoverleed/ certification/bd-c-new-construction/ > (accessed Feb. 5, 2015).

Weber, M. and Borcherding, K. (1993). "Behavioral influences on weight judgments in multi-attribute decision making." *Eur. J. of Oper. Research,* vol.67, 1-12.

Womack, J. P. and Jones, D. T. (1996). *Lean Thinking: Banish waste and create wealth in your corporation*. New York, NY: Free Press, Simon & Schuster, Inc., 1996, Second Edition, 2003.

Wu, P. and Low S. P. (2010). "Project Management and Green Buildings: Lessons from the Rating Systems.*" J. of Prof. Issues in Eng. Educ.Pract.,*136 (2),64-70.

Yin, R. K. (2003). *Case Study Research,* Sage Publications, 3rd ed., Thousand Oaks.

CHAPTER 2

IDENTIFICATION OF WASTE AND RELATED ROOT CAUSES IN GREEN BUILDING PROJECT DELIVERY PROCESS

2.1. Introduction

"Green" or "sustainable" buildings are high performance buildings that use energy, water, materials and land more efficiently than non-green buildings (NGBs) (Korkmaz et al., 2010b). Although GB projects are cost-effective in the long term due to lower operational and maintenance costs (Kats et al., 2003), higher initial capital cost demotivate stakeholders to invest in GB projects (Hall and Purchase, 2006; Williams and Dair, 2007; Robichaud and Anantatmula, 2011). According to a survey performed with 718 executives, higher construction cost was ranked as the most dominant obstacle to the GB projects although GBs enable lower operation and maintenance costs, higher market value, and impact on brand/reputation and customer requirements (Turner, 2012).

A previous study determined that the cost premium of LEED® (Leadership Energy Environment & Management) Gold and Platinum certified GB projects were approximately 2%-6.5% of project cost (Kats et al., 2003). This additional cost includes tangible costs, such as the elevated initial cost of high performance (HP) energy efficient technologies (e.g. HVAC systems), and innovative green materials (Stegall, 2004; Nilson, 2005; Zhang et al., 2011). Besides the tangible cost of GB features; there are also some hidden costs that lead to increase total project cost. These hidden costs are not considered in the initial premium cost calculations, such as the costs of increased architectural and engineering design effort (e.g superinsulated building envelopes), lower productivity and additional time spent for reworks (Robichaud and Anantatmula, 2011). The majority of these hidden costs can be attributed to waste in the processes (Porter and van der Linde, 1995; Pulaski et al., 2003; Riley et al., 2004).

Waste is defined as non-value adding activities (NVA) that absorb resources/cost but do not create any additional value for the project (Womack and Jones, 1996). A study conducted on a LEED® Gold certified building presented that 68% of the 124 activities throughout the sustainable building delivery process included waste and only the remaining 32% provide some added value (Lapinsky et al., 2006). Although this study analyzed and quantified the percentage of waste in a GB delivery process, the waste types were not described clearly and no discussions were made on underlying reasons of waste. Previous researches show that GB projects are generally more complex in comparison with the NGBs and have some specific types of waste due to their collaborative and interdisciplinary nature to respond for the needs of interconnected green design systems (Riley et al., 2004; Lapinsky at al., 2006). However, research studies on waste in GB project delivery process are limited, and most of the previous studies that investigated waste types in construction industry focused on non-green building (NGB) projects (Koskela, 1992; Josephson, 2003; Simonsson et al., 2012). Majority of the previous GB studies have analyzed the major barriers for GB projects; and only a small number of studies examined process waste in GB project delivery (Pulaski et al., 2003; Riley et al., 2004; Lapinsky et al., 2006; Horman et al., 2006).

In order to decrease the waste and associated hidden costs, and to motivate owners to invest in GB projects, waste types in GB project delivery process and underlying root causes of waste need to be identified and classified. Such a classification will help in developing models for streamlining the GB processes and minimizing the waste and related root causes that altogether allow to optimize GB project delivery and to ensure the successful completion of GB projects. This research study discussed in this chapter fulfills these gaps in the literature by examining waste and related root causes in detail for GB project delivery.

The objectives of this study explained in this chapter are (1) to identify and classify waste types, and their root causes that are observed in design and construction phases of GB project delivery process, (2) to rank the classified waste types and root causes based on their negative effects on time and cost in GB project delivery process. In order to achieve the first objective, an extensive literature review and a case study examining three GB projects were conducted, and the identified relationship between waste types and root causes represented in an Ishikawa diagram. To achieve the second objective, two-rounded Delphi method was applied on a panel of twelve experts, who are qualified in GBs and accredited by various areas of expertise. The findings of this research discussed in this chapter present the priority ranking of waste types and root causes based on their effects on time and cost.

2.2 Research Methodology

The research methodology performed to identify, classify and rank waste and related root causes for GB projects is presented in Fig. 2.1 by employing IDEF0 modeling language.

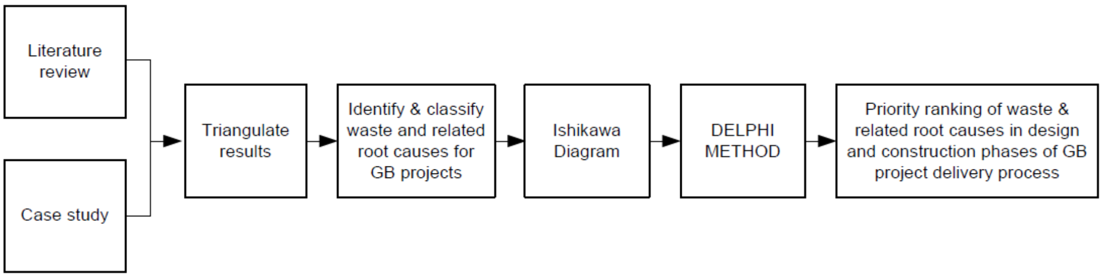

Fig 2.1: Research methodology for examining waste and root causes for GBs

In the first step of this study, a literature review and a case study were performed and the results were integrated to identify and classify major waste types and associated primary and secondary root causes in design and construction phases of GB project delivery process.

A broad review of the literature from 1992 to 2013 has been undertaken. With the aim of mitigating subjectivity, certain procedures based on keywords were employed in selecting and investigating publications (Betts and Lansley, 1993). Articles including in either of the following keywords were identified: ‘waste’, ‘process waste’, ‘wasteful activity’, ‘non value added time’, ’lean’, ‘lean construction’, ‘green building’, ‘sustainable building’, ‘project delivery’, ‘green building process’, ‘defect’, ‘waiting time’, ‘rework’, ‘delay’, and ‘cost of green building’. No limitations were adopted in the time frame; all the articles published in highly ranked journals (i.e. Journal of Construction Engineering and Management, International Journal of Project Management, Lean Construction Journal) were investigated. Each publication was manually reviewed to select the papers that include waste types, related root causes and their relationships to be included in the literature review. The studies that are included in the literature review are from different sources including reviews, thesis, case study and survey / interviews. All these publications are international and their authors are both academics and practitioners that would ensure multiplicity in the data gathered, allow comparative analyses, extend the research domain and bring different aspects together.

On the other hand, a qualitative case study was conducted for the same purpose. The case study includes three large scale GB projects of a general contractor, and data was collected using two methods: (1) Semi-structured interviews with five project team members, (2) participation at design coordination meetings that were performed biweekly/monthly by GB consultants, architects, civil engineers and engineers in a high performance (HP) green hospital project. Both in the interviews and in the design coordination meetings, the waste types and root causes in GB projects were identified. Conducting such a case study ensures to examine waste types and associated root causes in detail throughout GB project delivery process.

The results of the literature review and case study were triangulated to identify and classify waste types, and related primary and secondary root causes in GB project delivery process. The cause-effect relationships among the waste types and root causes were illustrated on an Ishikawa diagram (Banawi, 2013). The results were presented to the interviewees for getting their feedback to validate the findings.

Finally, Delphi method was used for ranking classified waste types and correlated primary and secondary root causes. This method obtains rational judgments from a preselected group of experts through series of questionnaires (Brown, 1968). A list of classified waste types and their primary and secondary root causes were distributed to twelve panelists for ranking. Two structured rounds were performed to minimize possible uncertainty among experts. The results were analyzed by using MS Excel and were checked for convergence using standard deviation (SD).

2.3 Background on Case Study

A case study was conducted to extend the results of the literature review and to perform an in-depth analysis for identifying waste and related root causes in the processes. Table 2.1 presents the details of the three GB projects that were included in the case study. These three construction projects are located in Turkey. The first project consists of 1500 residential units in five towers, a five star hotel, a congress facilities and offices. This project is a mix-use green development project. The second project is a green hospital project, and it is a 1200-bed HP hospital having 6 blocks and 576 seismic base isolators. The construction of these two projects was performed by the same construction company. The third project includes a 250 m tower with residences, a shopping mall, home offices and 40 m long shopping avenue. This HP green project is a joint-venture project of the same contractor company. Five members of a construction company were interviewed and eighteen design coordination meetings were attended to capture the waste types and the root causes as they are being discussed by the project team members. Table 2.2 gives the background information of the interviewed team members and the projects that they were associated with.

Table 2.1: Overview of the selected GB projects

Features	Project-1 (P1)	Project-2 (P2)	Project-3 (P3)
Project Type	High performance mix-use green project	High performance green hospital project	High performance mix-use green project
Building Type	Residential	Hospital	Residential
Project Content	• 1500 residential units in 5 towers • Hotel & congress center • Offices	• 1200-bed hospital • 6 blocks • 576 seismic (base) isolators	• 250m tower including residences and home offices • Shopping mall • 400m long street
Construction Area	372.000 sqm	210.000 sqm	700.000 sqm
GB Rating Systems	LEED2009 for New Construction	LEED2009 for Hospitals	LEED2009 for New Construction
Level of GB Certification targeted	LEED Gold Certificate	LEED Gold Certificate	• LEED Gold Certificate • BREEAM

Table 2.2: Background information of the interviewees

Profession	Experience (years) in		Education Degree	Professional Degree in GB rating systems		GB Projects
	Construction Industry	GB Projects				
Civil & Environmental Eng.	5-10	>5	M.Sc	LEED AP	BREEAM Asses.	P1&P2
Architect	5-10	≥5	Bachelor	-	-	P1
Electrical Engineer	>10	1-5	M.Sc	-	-	P2
Mechanical Engineer	5-10	1-5	Bachelor	-	-	P2
Mechanical Engineer	5-10	1-5	M.Sc	-	-	P1&P2

2.4 Classification of Waste in GB Project Delivery Process

When the data from literature review and case study were integrated, six common types of waste, and four primary root causes including sixteen secondary root causes were identified. Table 2.3 lists the identified waste types, the source of data and in which phase each waste type is observed.

Table 2.3: Waste types for GB project delivery process

ID	Waste type	Literature & case study Design	Construction	Related papers
w#1	Defects / revisions / reworks	+	+	Porter and van der Linde, 1995; Riley et al., 2003; Riley et al., 2004; Horman et al., 2004; Horman et al., 2006; Lapinsky et al., 2005; Lapinsky et al., 2006; Nahmens, 2009; Korkmaz et al., 2010a; Lai and Lam, 2010; Hwang and Ng, 2013; Magent et al., 2005; Sprau, 2009.
w#2	Value / quality loss (e.g. owners' / customers' dissatisfaction)	+	+	Porter and van der Linde, 1995; Riley et al., 2003; Riley et al., 2004; Horman et al.,2004; Beheiry et al.,2006; Lapinsky et al., 2005 ; Lapinsky et al., 2006; Kibert, 2007; Williams and Dair,2007; Nahmens, 2009; Korkmaz et al., 2010a, 2010b; Lai and Lam, 2010; Hakkinen and Belloni,2011;Jarrah and Siddiqui,2012.
w#3	Excessive documentation	-	+	Pulaski et al., 2003; Stegall, 2004; Nilson, 2005; Wiley et al., 2010; Robichaud and Anantatmula, 2011; Turner, 2012; Sprau, 2009.
w#4	Prolongation and overprocessing of design	+	+	Porter and van der Linde,1995; Riley et al.,2003; Riley et al., 2004; Horman et al., 2004; , Horman et al.,2006; Ofori and Kien,2004; Lapinsky et al., 2005; Beheiry et al., 2006; Williams and Dair,2007; Lam et al.,2009; Korkmaz et al., 2010a; Zhang et al., 2011; Jarrah and Siddiqui,2012; Hwang and Ng, 2013; Banawi, 2013; Sprau, 2009; Molenaar, 2010; Gultekin et al., 2013; Riley and Horman, 2005; Magent et al., 2005.
w#5	Elevated initial cost of GB requirements	+	+	Porter and van der Linde,1995; Cassidy,2003; Pulaski et al., 2003; Smith, 2003; Riley et al., 2003; Riley et al., 2004; Meryman and Silman,2004; Mogge, 2004; Ofori and Kien, 2004; Stegall, 2004; Nilson, 2005; Hall and Purchase, 2006; Lapinsky et al., 2005, 2006; Williams and Dair, 2007; Lam et al., 2009; Swarup et al., 2011; Hwang and Tan, 2010; Korkmaz et al., 2010a,b; Hakkinen and Belloni, 2011; Robichaud and Anantatmula, 2011;Shresta and Pushpala, 2012; Turner, 2012; Marphi, 2014; Hwang and Ng, 2013; Sprau, 2009; Riley, 2009; Gultekin et al., 2013.
w#6	Longer wait time	-	+	Pearce and Vagenas, 2002;Riley et al., 2003; Meryman and Silman, 2004; Tagaza and Wilson, 2004; Lapinsky et al., 2006; Williams and Dair, 2007;Lam et al., 2009; Nahmens, 2009; Bon and Hutchinson, 2010; Lai and Lam, 2010; Wu and Low, 2010; Hakkinen and Belloni, 2011; Robichaud and Anantatmula, 2011; Hwang and Ng, 2013; Banawi, 2013; Molenaar, 2010; Sprau, 2009.

The classified waste types that were observed in GB project delivery process are briefly explained as follows:

Defects/revisions/rework:

Defects are defined as "the non-fulfillment of intended usage requirements" (Josephson, 2003) and indicate production of defective parts that need to be repaired, reworked or revised requiring certain amount of non-value added time and effort to correct (Liker and Meier, 2006). Defects non-value added revisions and reworks are more commonly observed in GB project delivery process that are delivered through conventional project processes compared to NGB projects (Horman et al., 2004). These lead to undesired complexities in GB processes (Kibert, 2007). Defects in project design often lead to greater problems in the overall process of GB project delivery in the forms of unavoidable revisions; site defects and construction rework activities that entail certain time delays and additional costs (Forbes and Ahmed, 2011; Hwang and Ng, 2013). For this reason, in the early phases of the project a team of collaborative engineers need to perform detailed project design analysis to minimize any possible defects, revisions, rework and possible risk of increased costs through change orders in the subsequent stages of the project (Horman et al. 2004; Horman et al. 2006; Riley et al., 2004; Lapinsky et al., 2006; Hwang and Ng, 2013).

Value/quality loss:

Value in a project points out accomplishment of customer requirements (Koskela, 1992). On the contrary, value/quality loss refers to owners' dissatisfaction regarding the project cost, time and quality performance. Value/quality loss in GB project delivery often arise when the owners' requirements do not align with GB requirements (Porter and van der Linde, 1995; Korkmaz et al., 2010b) since in the GB scope, value should be generated for the end-user, the Owner and the environment as an additional customer (Huovila and Koskela, 1998; Horman et al., 2004). Owner's interests naturally align with higher profits, higher quality and shorter delivery of the product (Korkmaz et al., 2010b). While GB requirements aim to achieve higher level of sustainability, the owners generally focus on decreasing the additional costs and time while increasing the customer satisfaction and the market value of the project as well as the value of brand/reputation (Turner, 2012). Thus, involvement of the owner and the key project team members in early stages of GB projects allow them to find a common ground that would help fulfill both the owners' and the GB requirements (Lapinsky et al., 2006; Riley et al., 2005; Gultekin et al., 2013; Swarup et al., 2011). If project scope is not exactly specified at the beginning of the project, this might generate non-value added activities that should be streamlined.

Excessive documentation:

Detailed documentation is a requirement for the GB rating systems that lead to possible GB certification. In order to attain GB certification (e.g. LEED®), project design should reflect all necessary GB specifications that shall be integrated into the construction documentation, and they need to be compiled and submitted in full order. The intricate steps of documentation process required in GB certification are necessary for proving (1) Owners' Project Requirements (OPR), (2) basis of design (BOD), (3) characteristics of materials, equipment and technologies used in construction, and (4) performance verification of technologies, specifying the energy efficiency features of high performance GB projects (USGBC, 2009). According to a research study, among the participants who stated that their companies were not interested in LEED certification (52%), 79% of them indicated that one of the main reasons was staff time required due to detailed documentation (Turner, 2012). Among these participants, 75% of them believe that certification systems (e.g. LEED®) prolong the process (Turner, 2012). This corroborates with the findings of the case study. In the interviews with GB project participants, it was stated that GB certification process generally takes more time, and if there is no sufficiently qualified personnel in the project to carry out the process, new qualified personnel and/or specialized consultants might be needed. Hence, excessive documentation for GB certification can be characterized as a waste from the point of the owner, general contractor and employee considering design and construction phases of GBs if the owner selects to pursue a GB rating system. However, there is (perceived) additional value over GB alone, which would offset some of the waste identified.

Prolongation and overprocessing of design:

Although this is also a common waste encountered in NGB project delivery process, it is more significant for GB design and construction phases. Prolongation and overprocessing arise due to complex project design, cutting-edge interdisciplinary design analysis, highly specific material and technology selection, and interconnected green systems design (Riley et al., 2004; Robichaud and Anantatmula, 2011). This waste arise from defects/revisions, inefficiencies, downtimes, bottlenecks in the information flow, wait time due to lack of design integration, and change orders (Riley and Horman, 2005; Horman et al., 2006; Lapinsky et al., 2006; Banawi, 2013).

To decrease this waste, significant decisions related to the project scope and features should be made before or at the beginning of design phase by key project team members from different disciplines. Any change in opinions occurring in the later stages of design results in considerable prolongation and overprocessing. This also leads to unexpected delays in construction phase (Forbes and Ahmed, 2011). Prolongation and overprocessing not only elongate the activity durations but also increase the cost of the project if change orders occur to meet the mandatory GB requirements and the owners' demands (Robichaud and Anantatmula, 2011; Shresta and Pushpala, 2012). However, this not always the case, particularly when passive systems replace active ones or "elegant solutions" are achieved.

Elevated initial cost of GB requirements:

This waste relates to higher costs of high quality green materials (e.g., recyclables, low-VOC (volatile organic compound) materials), specially designed high performance energy efficient systems (e.g., HVAC systems, composting systems), and also GB certifications and documentation submittals (Stegall, 2004; Nilson, 2005; Shresta and Pushpala, 2012). Elevated costs result from the scarcity of energy efficient products that are overvalued in the market (Robichaud and Anantatmula, 2011; Hwang and Ng, 2013). This situation possibly arises from unavailability of green product leaders in the industry that would drive the production and distribution of energy efficient materials and technologies (McGraw-Hill Construction, 2006; Robichaud and Anantatmula, 2011). Introducing suppliers at the early phases would ensure accurate choice of products by allowing time to eliminate any doubts and debates regarding the true value of the products (Vrijhoef and Koskela, 2000). If green products are expanded to new markets and they are produced in greater amounts parallel to the increasing need of GB industry, cost of GB requirements might not be categorized as a type of waste as the overall prices of energy efficient products would decrease (Lockwood, 2006; Lam et al., 2009; Robichaud and Anantatmula, 2011).

Longer wait time:

In this study, wait time refers to time spent for waiting between activities/tasks in design and construction, and relates to supplying products. Considering the interviews with project participants, wait time is longer in GB project delivery process compared to the wait time in NGB projects due to design of interrelated green systems associating with different disciplines. This information corroborate with the findings of literature review. Selection and supply of green materials and technologies are complicated processes that are accompanied by long wait time which generally arise from inefficiencies, downtime, and bottlenecks occurring in the work, material and information flows (Horman et al., 2004; Lapisnky et al., 2006; Hwang and Ng, 2013). Although supply delay is also a significant waste in NGB project delivery process, it is more frequently encountered in the GB project delivery process as GB is still a novel subject in the construction industry (Lam et al., 2009; Wu and Low, 2010). The green supply market is still not fully developed and regional green product suppliers are often insufficient at responding to all the demands and expectations of GB projects (Lam et al., 2009; Jarrah and Siddiqui, 2012). Due to the scarcity in the green market, supplying energy efficient materials and systems over longer distances are often required and this results in increased costs and longer wait time in supply chain. According to the interviews with project participants, wait time can be encountered not only in the supply chain but also during installation of advanced green design solutions at construction site. Implementing HP energy efficient systems/equipment at site is difficult and could take longer time, including additional wait time to fix the problems. Inexperienced subcontractors could cause defects and delays in workflow during implementation of green systems (Syal et al., 2007; Banawi, 2013; Hwang and Ng., 2013).

2.5 Classification of Root Causes of Waste in GB Project Delivery Process

The findings of the study show that waste types in GB project delivery process have four groups of primary root causes and sixteen secondary root causes. These root causes are generally based upon the project delivery attributes which can be classified as *GB project* and *GB project team related root causes*. The relationship among the waste types, primary and secondary root causes are represented in an Ishikawa Diagram and the primary root causes are explained in the following sections (Fig. 2.2).

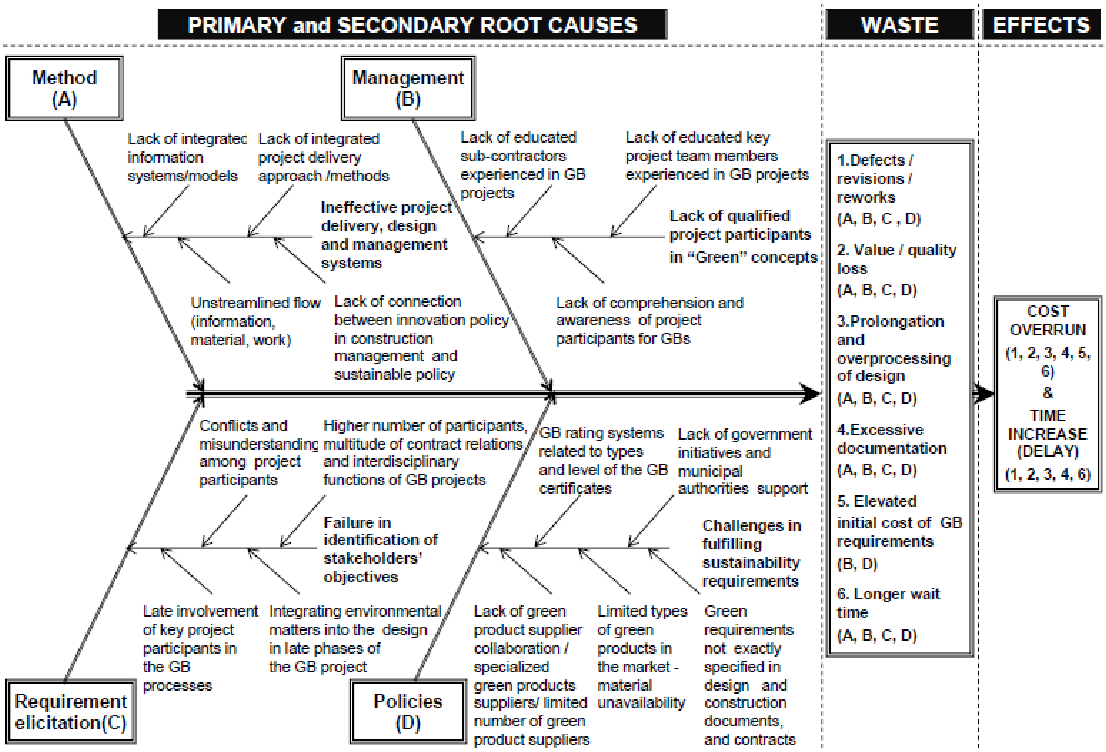

Fig 2.2: Ishikawa diagram for waste and related primary and secondary root causes

2.5.1 Ineffective Project Design, Delivery, and Management Practices

This primary root cause is related to GB project attributes and it consists of four secondary root causes (Figure 2.1A): (1) lack of integrated information models/systems, such as Building Information Modeling (BIM), (2) lack of integrated project delivery (IPD) approach/model/methods, such as lean construction, (3) unstreamlined information, material and work flow, and (4) lack of integration between innovation policy in construction management and sustainable policy (Pulaski et al., 2003; Smith, 2003; Lapinsky et al., 2006; Swarup et al., 2011; Robichaud and Anantatmula, 2011; Banawi, 2013; Hwang and Ng, 2013).

To achieve efficient design and construction phases, GB projects require more collaborative, interdisciplinary and innovative approach than what conventional methods could provide (Porter and van der Linde, 1995; Riley et al. 2004; Lapinsky et al., 2006; Hwang and Ng, 2013; Robichaud and Anantatmula, 2011). If GB project team omits to use integrated information models (e.g., BIM), it would lead to series of inevitable defects, revisions, rework (w#1) and prolongation and overprocessing of design (w#3), which arise due to the interconnected nature of the green systems designed by different parties. These possible revisions/reworks would create even more excessive and challenging documentation (w#4) along with them, as each revision needs be documented for GB certification purposes.

On the other hand, it would be much more difficult for a GB project delivery process to be successful without the use of integrated project delivery (IPD) methods. Conventional delivery methods (e.g. Design-Tender-Build) cause problems in the identification of requirements, communication and data transmission in GB project delivery process (Magent et al., 2005; Syal et al., 2007; Lam et al., 2009; Hwang and Ng, 2013). Conventional methods create a negative impact on the tentative balance between the GB and owner’s requirements, and this creates inefficiencies regarding the material and information flow. Consequently, it increases wait time in the supply chain (w#6) and cause value/quality loss in the project (w#2).

Similarly, unstreamlined information, material and work flows also relate to activities that create waste throughout the processes (Banawi, 2013). According to the interviews performed with GB practitioners, unstreamlined flows laden with defects/revisions/reworks throughout GB design and construction phases (w#1) and mostly lead to prolongation and overprocessing of design (w#3) due to data loss. They point out that troubles in coordination, communication and data transmission promote unstreamlined flow. These results corroborate with previous studies. A study conducted by Sprau (2009) presents that lack of communication, specifically in the projects pursuing LEED certification, lead to schedule delays (Sprau, 2009). Increase in number of project participants and project requirements also result in unstreamlined flows when conventional methods/ models are used in GB processes (Magent et al., 2005). Hence, developing a method or tool is highly suggested to streamline documentation process of GB certification to overcome additional labor costs and time that emerge from the certification requirements (Stegall, 2004). Suppliers that get involved in the GB processes late also trigger unstreamlined information, material and work flows; thus generating longer wait time in supply chain (w#6).

Lack of integration between innovation policy in construction management and sustainable policy would effectively increase all types of the waste encountered in GB project delivery process (Banawi, 2013). For example, utilizing conventional project delivery methods in GB projects can generate more waste throughout GB project delivery process (Magent et al., 2005). The innovative systems can facilitate tasks and applications carried out in design and construction phases by streamlining processes. Thus, by using innovative efficacious systems for GBs help diminish overprocessing, wait time, defects; thereby, initial cost decreases and quality/value in the project increases.

2.5.2 Lack of Qualified Project Participants in "Green" Concepts

This primary root cause is associated with project team attributes and includes three root causes (Fig. 2.1B): (1) lack of educated subcontractors experienced in GB projects and features, (2), lack of educated key project team members experienced in GB projects and requirements, and (3) lack of comprehension and awareness of project participants for GBs and requirements. These secondary root causes closely correlate with lower productivity. Inclusion of highly qualified project team members is a critical necessity for the success of GB project delivery process since GBs are relatively new concepts that need advanced solutions in design and construction phases (Lam et al., 2009; Sprau, 2009; Robichaud and Anantatmula, 2011; Hwang and Ng, 2013). A study highlights that project teams having more experiences in LEED requirements and certification provide a decrease in cost related to LEED certification (Mapp et al., 2011). On the contrary, project teams with little or no experience in LEED® requirements and certification provide an increase in costs associated with LEED® certification.

Construction subcontractors without sufficient education and experience in GBs would most likely encounter problems while implementing these advanced energy efficient systems on site (Syal et al., 2007; Banawi, 2013; Hwang and Ng, 2013). Specifically, subcontractors' education in GB project delivery process has an impact on schedule growth (Gultekin et al., 2013). These information emphasize the importance of subcontractors' education and experience for the success of GB projects (Syal et al., 2007; Korkmaz et al., 2010b; Jarrah and Siddiqui, 2012; Hwang and Ng, 2013).

Moreover, it is important that key project team members (e.g., project manager, contractor) have sufficient experience, education and awareness in green processes to find the most feasible design solution for the project considering owners' budget and priorities (Riley et al., 2003; Chan et al., 2004;Wu and Low, 2010).

Particularly, the contractor's experience has a crucial impact on the achievement of green goals, schedule control and cost control (Gultekin et el., 2013). For example, within LEED® 2009 for New Construction and Major Renovations (NC and MR) rating system, there are many options on how to fulfill each environmental criterion from which the project team needs to select the most appropriate solution for their particular case. If, due to lack of education and experience, the key GB project team members cannot make right decisions on which of these options and environmental criteria are feasible for the owner's priorities and projects' specifications, they would inevitably cause various types of waste. For example, increase in time and cost overruns through series of defects/revisions/rework (w#1), prolongation and overprocessing (w#3) and longer wait time (w#6). Consequently, these waste types decrease the quality/value in the project (w#2) and fail to fulfill the owners' and GB requirements. Additionally, lack of educated and experienced project team members is likely to result in difficulties when creating documents needed for GB certification (w#4); thereby, decreases the productivity. Surveys performed in 2009 and 2012 respectively show that 33% and 40% of executives prefer to hire extra qualified employees for GB projects to overcome challenges in GB design, certification and construction phases despite of the additional cost (Turner, 2012).

2.5.3 Failure in Identification of Stakeholders' Requirements

This primary root cause is highlighted as one of the main reasons for elevated cost and time (Chan et al, 2004; Williams and Dair, 2007; Syal et al., 2007; Sprau, 2009; Swarup et al., 2011; Hakkinen and Belloni, 2011). It includes four types of secondary root causes (Fig. 2.1C): (1) late involvement of key project participants in GB processes, (2) integrating environmental matters into the design in later phases of the GB project, (3) conflicts and misunderstanding among stakeholders, (4) higher number of project participants, multitude of contract relations and interdisciplinary functions of GB projects. This primary cause relates to partially GB project attributes (i.e. interdisciplinary structure, project delivery method) and fundamentally originates from GB project team attributes such as team structure, cross-disciplinary work, owner's commitment to green matters, owner's ability to make decisions and define the project scope (Beheiry et al., 2006; Korkmaz et al., 2010b; Gultekin et al., 2013). GB project designs are characteristically executed by greater number of project participants from different disciplines (Pulaski et al., 2003; Riley et al., 2004; Robichaud and Anantatmula, 2011). Thus, this complex structure of GB projects causes conflicts and misunderstanding among the stakeholders (Wu and Low, 2010). Moreover, multitude of contractual relations within GB projects causes conflicts among project parties as priorities of each project participant differ from each other. For example, while owners tend to overemphasize timely completion of the project and increased profits, GB consultants put great importance on the environmental performance of the building (Lai and Lam, 2010). These different expectations and mismatching motivations directly cause defects, revisions and rework (w#1), value/quality loss in the project (w#2), prolongation and overprocessing of design (w#3), and consequently excessive documentation (w#4) (Wu and Low, 2010; Robichaud and Anantatmula, 2011; Hwang and Ng, 2013).

Timely involvement of all key participants are crucial for the overall success of the project (Chan et al, 2004) as the owner, general contractor, commissioning agent (i.e. CXA), concept design architects are all important for the process of defining the project scope. Timing of project teams' involvement in GB processes has been highlighted to obtain better project outcomes in terms of time, cost, quality and sustainability (Gultekin et al., 2013; Korkmaz et al., 2007; Molenaar et al., 2010; Swarup et al, 2011). Particularly, timing of the contractor's involvement in the GB project delivery process has an important impact on the successful completion of the project in terms of time, cost and sustainability (Gultekin et al., 2013). In the case key project participants join in late stages of the project, stakeholders' requirements are hardly defined (Riley et al., 2004; Syal et al., 2007; Korkmaz et al., 2010b; Hwang and Ng, 2013). As a result, it would lead to defects, revisions and reworks (w#1) and prolongation and overprocessing (w#3). Each revision resulting from change orders causes additional documentation (w#4). Hence, this root cause leads to value/quality loss in the project (w#2). Timely integration of environmental matters into design is also important since it could possibly have negative impact on the success of GB projects regarding the identification of owner's particular needs and project requirements (Williams and Dair, 2007; Riley et al., 2003; Swarup et al.,2011; Korkmaz et al.,2010b; Robichaud and Anantatmula, 2011). In fact, identifying owner's project objectives have a critical impact on the success of cost, time and green goals (Gultekin et al., 2013). Late integration of environmental matters creates waste types as the previous root cause does. In addition, these two root causes lead to breakdowns in information, material and work flow; therefore, leads to longer wait time (w#6). Although conflicts and misunderstanding among stakeholders can be also experienced in NGB projects, these are more commonly encountered in GB projects due to high number of project participants from different disciplines. This secondary root cause is closely related to another root cause: multitude of contract relations and interdisciplinary functions of GB projects. Both of these secondary root causes have negative effects on decision making processes by causing similar waste types as the previous secondary root cause (i.e. conflicts and misunderstanding among stakeholders). These root causes can be handled well by effective project delivery (Robichaud and Anantatmula, 2011).

2.5.4 Challenges in Fulfilling Sustainability Requirements

This primary root cause points out to one of the major reasons for complexity and difficulty in GB projects (Cassidy, 2003; Turner, 2012; McGraw-Hill Construction, 2006). This primary root cause is related to GB project attributes and consists of five groups (Fig. 2.1D): (1) limited types of energy efficient materials and technologies, (2) limited number of green product suppliers/specialized green product suppliers, (3) “Green” characteristics which are not exactly specified in the design and construction documents and in the contracts, (4) GB rating systems relating to type and level of the GB certificates, and (5) lack of government initiatives and municipal authorities’ support.

The first and second root causes relate to the scarcity of environmental materials in the market, especially in immediate surroundings. Unavailability of materials within the local markets results in higher transportation costs and eliminates any chance of discounted rates (Lam et al., 2009; Jarrah and Siddiqui, 2012). Similar to the GB materials, energy efficient technologies that need to be specially designed are also hard to find in the market and need to be imported from abroad (Stegall, 2004; Wiley et al., 2010; Robichaud and Anantatmula, 2011). However, supplying green products from longer distances is contradictory to sustainability concept. Instead, recycled/recyclable materials need to be supplied from the immediate surroundings as some GB certification credits relate directly to local material supply (Pulaski et al., 2003; Wu and Low, 2010). These limitations result in higher up-front costs (w#5) (Stegall, 2004; Nilson, 2005) and longer wait time in supply chain (w#6) (Lam et al., 2009; Robichaud and Anantatmula, 2011; Hwang and Ng, 2013). Although GB characteristics add value to the project with higher market value and lower operational and maintenance costs (Wiley et al., 2010), problems in material availability might also negatively affect value and quality of the project (w#2) due to dissatisfaction of owner, general contractor and/or customers in cost and time. The third secondary root cause is "Green" characteristics that are not exactly specified in the documents. This triggers defects/revisions/rework (w#1), prolongation and overprocessing of design (w#3) due to possible time consuming and costly change orders, and related excessive documentation (w#4). The forth secondary root cause, which is GB rating systems relating to type and level of the GB certificates, can induce these previously mentioned waste types if the environmental criterions are not adequately carried out.

The final secondary root cause in this category is the lack of government initiatives and municipal authorities' support, which is needed as GB projects are still not widespread and awareness needs to be increased. Government initiatives are likely to promote producing energy efficient products by regional suppliers and immediate surroundings. Currently regional suppliers are not adequate to fully respond to the needs of GBs (w#6); therefore, initial costs of green products are still elevated (w#5). Once government initiatives and local municipal organizations foster GB projects by legislations, investment in GB projects will rise. Hence, the demand to GB materials and energy saving technologies will increase, forcing the suppliers to produce different types of environmentally friendly materials and innovative energy efficient technologies to meet this growing demand (Hall and Purchase, 2006; Bon and Hutchinson, 2010; Robichaud and Anantatmula, 2011; Eichholtz et al., 2013). The competitiveness initiated in the market would allow for the price of green products to drop since the product choices would increase allowing the practitioners to find what they need in their immediate surroundings for much less transportation costs and higher GB certification credits attained. Additionally, if tax incentives and property cost saving options are offered by the governments, brown-fields or any other damaged sites could be rehabilitated if they are selected for GB projects. This would further help to gain more GB certification credits (USGBC, 2009).

2.6 Delphi Method

The goal of using Delphi method in this study described in this chapter is to rank the classified waste, and associated root causes in design and construction phases based on their negative effect on the processes in GB project delivery. The Delphi process performed to achieve this objective is illustrated in Fig. 2.3.

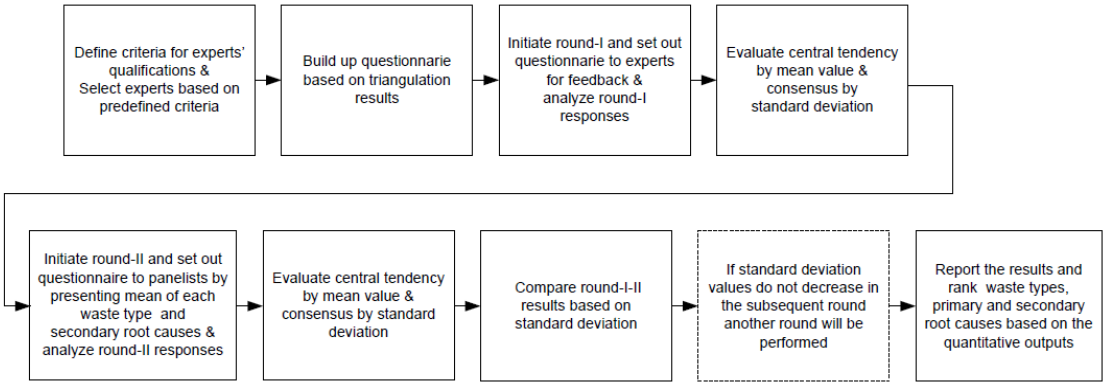

Fig 2.3: Tasks involved in the Delphi Process for ranking waste and root causes in GB project delivery process

In this method, panel members were asked to rank the list of waste types and root causes in two rounds to ensure that a consensus is reached. The first step of the Delphi Method is to define the criteria for expert's qualifications to ensure that they have sufficient knowledge and experience in the GBs (Hallowell and Gambatese, 2010). It is expected that experts meet at least one criterion from each of the following two groups: (1) knowledge/education level, (2) experience level. Criteria for knowledge/education level are: (1) to be at least a LEED® Accredited Professional (LEED AP) or a BREEAM® International Assessor, (2) to have education degree (at least Bachelor) related to construction, (3) to have professional degree in their subjects, such as Project Management Professional (PMP). Criteria for experience level are: (1) having worked or is currently working in one of the projects in the case study (i.e. P1, P2 and P3), (2.2) at least three years professional experience in construction industry, (2.3) at least one year professional experience in GBs. Based on these criteria, twelve experts were selected among GB consultants and project team members (e.g. PM).

Besides project team members who are highly qualified in GBs, these GB projects also include personnel with little or no experience and education in GBs who could cause the survey to provide faulty results if they are selected as panel members. This barrier was overcome by carefully selecting panel participants based on the predefined qualification criteria which ensures that all panel members have sufficient knowledge and experience in the GBs. Project team members involved in this Delphi Inquiry were selected among the most experienced and educated personnel employed in these three GB projects that are examined for this case study.

In order to provide multiplicity in the outputs and to combine experiences in different professions, experts were selected from different departments of the GC Company and GB Consulting Companies working on these three GB projects. GB Consultants participated in this Delphi Inquiry work internationally. One of the experts was the Commissioning Agent from U.S. and provided LEED Fundamental Commissioning one of these three GB projects. Qualifications of the selected panel members can be found in Table 2.4.

Table 2.4: Panel members participating in Delphi process for ranking waste and related root causes in GB project delivery process

Profession/Position	Experience (year) in Construction Ind.	GBs	Degree	Professional Degree in GB Rating Systems		Current Project
Civil Engineer & PMP / GB Consultant	>10	>5	M.Sc.	LEED AP	BREEAM Int. Assessor- In-Use Auditor	P2
Architect / GB Consultant	>10	>5	MArch	LEED AP	BREEAM Int. Assessor	P2
Mechanical Eng. / GB Consultant	>10	>5	Bachelor	LEED AP	-	P1
Civil & Environmental Eng. / GC – GBs & Coordination Responsible	5-10	>5	M.Sc.	LEED AP	BREEAM Int. Assessor	P1&P2
Mechanical & Industrial Eng. / GC - Head of Business Development Dept.	>10	>5	M.Sc.	-	-	P1& P2&P3
Architect / GC - Project Manager	>10	>5	M.Arch	-	-	P1
Architect & Interior Designer / GC - Tech.Office & Coor. Dept.- Specialist	5-10	>5	M.Arch	LEED AP	BREEAM Int. Assessor	P1
Architect / GC – Manager of Business Development Dept.	5-10	>5	M.Arch	-	-	P1& P2&P3
Architect / GC – Tech. Office & Coor. Dept. -Specialist	5-10	≥5	Bachelor	-	-	P1
Architect / GC – Procurement Dept. – Specialist	5-10	1-5	M.Arch	LEED GA	-	P1&P2
Civil Engineer / GC – Cost and Planning Dept. - Specialist	5-10	1-5	M.Sc.	-	-	P2
Architect / GC – Tech.Office & Coor. Dept.- Specialist	5-10	1-5	M.Arch	-	-	P2

The second step was to create a questionnaire building upon the results of literature review and case study. This questionnaire was distributed to panel members in two rounds that was strongly suggested to achieve more specific consensus among panelist (Dalkey et al., 1972). In the first round, a list of waste and related primary and secondary root causes for GB projects were presented to the panel members, who were asked to score each of them by using five-point Likert-scale. In this grading system, "1" indicates "without any negative effect" while "5" corresponds to "very high negative effect". Mean, median and standard deviation (σ) were calculated for each waste type and root causes based on the scores given by the panelists. Mean, and median values are the measures of central tendency (Dalkey, 1969), and the standard deviation (SD) is the measure of group consensus and used for ranking the variables (Gunhan and Arditi, 2005a, 2005b; Hallowell and Gambatese, 2010). The waste types and root causes were ranked according to the associated mean value. If mean values of two waste types or root causes are equal, median values were used for ranking. Standard deviation is used to compare the consensus at each round. When SD drops in consecutive rounds it means that consensus has been reached. For this reason, SD is expected to decrease from one to the next round. SD less than 1 indicates high level of consensus is achieved (Gunhan and Arditi, 2005b, Vidal et al., 2011). If consensus is not achieved, another round needs to be performed.

2.6.1 Priority Ranking of Waste for GB Project Delivery Process

Based on mean, median and standard deviation calculated from points received in round-I&II, waste types are ranked for design and construction phases of GB project delivery process (Table 2.5). In the first round, standard deviation of some of the wastes and secondary root causes are greater than 1. Therefore, a second round was performed. The mean of each waste type were presented to panelists and they scored the waste types for the second time considering mean values. In this round, the experts also indicated the reasons if they did not agree with the given scores. In the second round, standard deviations were lower compared to the first round and all values were less than 1, indicating that a high level consensus was reached among panel members.

Performing interactive rounds and providing controlled feedbacks allow researchers achieve higher reliability and quality in outputs (Mitchell, 1991; Rowe et al., 1991). Hence, Delphi Method, based on the iterative rounds and controlled feedback, ensures that outputs from this qualitative procedure do not need to be test-retested (i.e. t test, Kendall's tau-b, Scheffe test (post-hoc comparisons)) to control the reliability of data (Okoli and Pawlowski, 2004; Hasson and Keeney, 2011). In Table 2.5, quantitative results from second round and priority ranking of waste types are represented.

Table 2.5: Ranking of waste for design and construction phases of GB delivery

Priority Ranking of Waste in GB Project Delivery Process								
Rank	**Design Phase**	**Mean**	**Median**	**SD**	**Construction Phase**	**Mean**	**Median**	**SD**
1	Defects/revisions /reworks	4.17	4.00	0.58	Defects / revisions /reworks	4.17	4.00	0.39
2	Prolongation and overprocessing of design	4.08	4.00	0.51	Excessive documentation	3.67	4.00	0.89
3	Value/quality loss	2.92	3.00	0.51	Elevated initial cost of GB requirements	3.58	4.00	0.67
4	Elevated initial cost of GB requirements	2.83	3.00	0.83	Prolongation and overprocessing of design	3.33	3.00	0.49
5	Excessive documentation	1.92	2.00	0.51	Longer wait time	3.25	3.00	0.75
6	Longer wait time	1.83	2.00	0.94	Value / quality loss	3.17	3.00	0.72

According to the rankings results, the most important waste is the *defects/revision/reworks* both for design and construction processes of GBs. The rest of the ranking has some differences for the design and construction processes. As GBs are interdisciplinary design–based innovative systems, "*prolongation and overprocessing of design"* is the second important waste for design phase. These two waste types are the most significant ones in the design phase since they are the only waste types that have mean values above four out of five. "V*alue/quality loss" and "elevated initial costs of GB requirements"* are the third and forth important waste types in design phase. Having scores below two, "*excessive documentation" and "longer wait time"* are the least important waste types. The reason of having very low scores is both *"documentation"* and *"longer wait time"* are mostly observed in construction phase.

On the other hand, in construction phase the scores of waste types do not vary a lot and ranges from 3.17 to 4.17. As there is not a big difference among their scores of significance, it can be stated that all waste types have highly negative impacts on construction phase. One reason for the negative effects of waste types being higher in construction phase is that design phase are likely to overlap with construction (Glavinich, 2008). This indicates that the negative influence of each waste type encountered in design is transferred to construction phase; thus, complexity in construction phase is higher than that of design. According to the interviews, if waste that is occurred in design is not eliminated, it triggers waste generation in construction phase. The second most important waste type is "*excessive documentation*" in construction phase since most of the GB certification documentation are prepared throughout the construction phase till the completion of the project. "*Elevated initial cost of GB requirements"* is ranked as third. The reasons are that the payments of green products are generally made during this phase.

2.6.2 Priority Ranking of Root Causes in GB Project Delivery Process

Priority ranking of root causes was performed for determining the significance of each root cause on waste generation in design and construction phases of GB project delivery process. Table 2.6 presents mean, median and SD values and resulting ranking of root causes. Only the secondary root causes were scored by the panel members; and the scores for primary root causes were determined by averaging the values of secondary root causes.

Table 2.6: Ranking of primary and secondary root causes in GB project delivery

Rank	Design Phase	Mean	Median	SD	Construction Phase	Mean	Median	SD
1	**Lack of qualified project participants in "Green"concepts**	**4.17**	**4.00**	**0.66**	**Failure in identification of stakeholders' requirements**	**3.75**	**3.88**	**0.69**
1.1	Lack of educated key project team members experienced in GB projects and features	4.25	4.00	0.62	Integrating environmental matters into the design in late phases of the GB project	4.50	5.00	0.67
1.2	Lack of educated sub-contractors experienced in GB projects and GB features	4.17	4.00	0.58	Late involvement of key project participants in the GB processes	4.25	4.00	0.62
1.3	Lack of comprehension and awareness of project participants for GBs and GB requirements	4.08	4.00	0.79	Higher number of participants, multitude of contract relations and interdisciplinary functions of GB projects	3.33	3.50	0.78
1.4	-	-	-	-	Conflicts and misunderstanding among project participants	2.92	3.00	0.67
2	**Failure in identification of stakeholders' requirements**	**4.02**	**4.25**	**0.57**	**Lack of qualified project participants in "Green"concepts**	**3.72**	**3.67**	**0.66**
2.1	Integrating environmental matters into the design in late phases of the GB project	4.67	5.00	0.49	Lack of educated sub-contractors experienced in GB projects and GB features	4.08	4.00	0.79
2.2	Late involvement of key project participants in the GB processes	4.67	5.00	0.49	Lack of educated key project team members experienced in GB projects and features	3.58	4.00	0.51
2.3	Conflicts and misunderstanding among project participants	3.50	4.00	0.67	Lack of comprehension and awareness of project participants for GBs and GB requirements	3.50	3.00	0.67
2.4	Higher number of participants, multitude of contract relations and interdisciplinary functions of GB projects	3.25	3.00	0.62	-	-	-	-
3	**Ineffective project delivery process systems and management practices**	**3.77**	**3.75**	**0.61**	**Ineffective project delivery process systems and management practices**	**3.67**	**3.75**	**0.83**
3.1	Unstreamlined flow (information, work, material)	4.08	4.00	0.51	Unstreamlined flow (information, work, material)	4.00	4.00	0.85
3.2	Lack of integrated building information models/systems	4.08	4.00	0.67	Lack of integrated project delivery approach/methods	4.00	4.00	0.85
3.3	Lack of integrated project delivery approach/methods	3.83	4.00	0.58	Lack of integrated building information models/systems	3.50	4.00	0.90
3.4	Lack of connection between innovation policy in construction management and sustainable policy	3.08	3.00	0.67	Lack of connection between innovation policy in construction management and sustainable policy	3.17	3.00	0.72
4	**Challenges in fulfilling sustainability requirements**	**3.15**	**3.30**	**0.76**	**Challenges in fulfilling sustainability requirements**	**3.55**	**3.60**	**0.81**
4.1	GB rating systems relating to type, and level of the GB certificates	3.75	4.00	0.75	Lack of green product supplier collaboration / specialized green product suppliers/ limited green product suppliers	3.92	4.00	0.90
4.2	"Green" requirements not exactly specified in design and construction documents, and the contracts	3.58	4.00	0.67	"Green" requirements not exactly specified in design and construction documents , and the contracts	3.75	4.00	0.75
4.3	Limited types of energy efficient materials and technologies in the market (material unavailability)	2.92	3.00	0.67	Lack of government initiatives and municipal authorities support	3.50	3.50	0.80
4.4	Lack of government initiatives and municipal authorities support	2.83	3.00	0.94	Limited types of energy efficient materials and technologies in the market (material unavailability)	3.42	3.50	0.90
4.5	Lack of green product supplier collaboration / specialized green product suppliers / limited green product suppliers	2.67	2.50	0.78	GB rating systems relating to type, and level of the GB certificates	3.17	3.00	0.72

Primary root causes related to GB project team attributes (i.e. lack of qualified project participants in "Green" concepts and failure in identification of stakeholders' requirements) are more significant in design phase than primary root causes associated with GB project attributes. In the construction phase, the scores of primary root causes do not vary on a large scale. Among the secondary root causes, "*late involvement of key project participants in GB processes"* and *"integrating environmental matters into the design in late phases of the GB project"* are the highest scored ones for design and construction phases. Since GBs are based on interdisciplinary green design systems and require complex design analysis, *"lack of educated key project team members experienced in GB projects"* and *"lack of educated sub-contractors experienced in GB projects"* are the third and fourth secondary root causes for design process. Additionally, *"lack of educated sub-contractors experienced in GBs"* is the third and *"unstreamlined flow"* and *"lack of integrated project delivery approach/methods"* are the forth secondary root causes for construction phase. In design phase, "*lack of comprehension and awareness of project participants for GBs"* and *"lack of integrated building information models/systems"* gained above 4 points while these secondary root causes got below 4 points in construction phase. Among the secondary root causes under 4 points in design and construction phases, "*government initiatives and municipal authorities support* "received higher scores from GB consultants than employees in GC company. This difference in point of view emphasizes the inherited difficulty for finding a consensus among different parties.

2.7 Discussions

The outputs of Delphi method shows that the top ranked waste is *"defects/revision/reworks",* for both the design and construction processes of GBs. Except *defects and revisions*, *prolongation and overprocessing of design*, waste types obtained higher points in construction phase compared to the design. Also, the scores of waste types do not vary on a large scale in construction phase compared to the design. This indicates that waste experienced in GB design is not eliminated and is transferred to the construction phase.

The outcome of this study explained in this chapter points out that primary and secondary root causes leading to waste in terms of time increase and cost overruns can be classified in two groups: Root causes that are related to (1) *GB project attributes*, and (2) *GB project team attributes*. Both of these are categorized under *GB project delivery attributes*. The former is driven by unique features, objectives and requirements of GB projects and consists of two primary root causes: *"ineffective project delivery, design, and management practices"*, and *"challenges in fulfilling sustainability requirements"*. The latter is driven by qualifications of project participants in GB projects together with the structure and the features of project teams and includes "*lack of qualified project participants in "Green" concepts*", and *"failure in identification of stakeholders' requirements"*. This research study discussed in this chapter show that primary root causes associated with GB project team attributes gained higher points in design and construction phases compared to the primary root causes related to GB project attributes. This finding points out that unqualified project teams in sustainable projects have considerable impact on waste generation in design and construction phases of GB project delivery process.

Results show that the priority ranking of primary root causes for design and construction phases of GB project delivery process is similar since the primary root causes identified are common for all GB processes. However, the priority ranking of the secondary root causes is greatly different for each phase. Similar to the ranking of secondary root causes, the priority ranking of the waste types is also highly different for design and construction phases of GB project delivery process. The reasons of these differences associated to ranking of waste types and secondary root causes for each phase can be related to these factors that are specific to each phase: (1) requirements, specifications and features regarding scope and objectives of each phase, (2) process-specific tasks executed to fulfill the particular requirements of each phase, (3) process-specific challenges that emanate from the features of each phase and belong to unique tasks required for each phase, and (4) project participants who play great roles for each phase and process-specific tasks.

When root causes are examined, it is clear that involving key project team members and integrating environmental matters at the beginning of GB project are crucial for the success of GB projects. To enable early involvement of key project team members and early integration of environmental aspects to the project, integrated project delivery methods, building information modeling and advanced document management tools are suggested. Moreover, employing highly qualified project team members, promoting regional suppliers for production of high performance energy efficient products will reduce the waste in design and construction phases of GB project delivery process.

2.8 Conclusions

This study classifies waste types and associated root causes, investigates their relationship and ranks them according to their negative impacts on time and cost in design and construction phases of GB project delivery process. The classification is presented on an Ishikawa diagram, which represents cause-effect relationship between waste types and primary root causes consisting of secondary root causes.

One of the most prominent findings of this research study is that the priority ranking of waste types for design and construction phases greatly differs from each other except for the top ranked waste, *"defects/revision/reworks"*, which is same for both the design and construction processes of GBs. The reason might be late integration of environmental aspects regarding OPR (e.g. LEED certification goals) in the phases of GB project delivery. A study conducted by Sprau (2009) presents that deciding to follow LEED certification after the design elevates rework and confusions (Sprau, 2009).

"*Prolongation and overprocessing of design"* is the second most important waste for the design phase, while "*excessive documentation"* is for the construction phase. The reason of this difference might be that project design teams should integrate all necessary GB specifications into the construction documentation, and they need to be compiled and submitted in full order. Previous researches corroborate with these findings of Delphi Method. According to a prior research performed with 718 GB executives, 75% of these GB executives (among 52% of 718 executives) believe that GB certification systems (e.g. LEED®) prolong the process. In case, 79% of them indicated that one of the main reasons for not seeking GB certification was staff time required for detailed documentation (Turner, 2012).

These three waste types underlined not only elongate activity durations but also lead to additional costs (i.e. hidden costs) to meet the mandatory GB requirements and the owners' demands (Robichaud and Anantatmula, 2011; Shresta and Pushpala, 2012). However, this not always the case, particularly when passive systems replace active ones or "*elegant solutions*" are achieved.

The results of Delphi Method also point out that the scores of most of waste types experienced in design phase are lower than that of waste types in construction phase. The reason might be that waste types which are observed in design phase cascade down to the next phase.

The results of Delphi Method indicates that priority ranking of primary root causes for design is almost the same for the construction process since the primary root causes are generic for GB projects and affect the whole GB project delivery process. "*Lack of qualified project participants in"Green"concepts"* and *"failure in identification of stakeholders' requirements"* gained the highest scores in design and construction phases among these primary root causes. Contrary to those, the priority ranking of secondary root causes for design phase is different from construction phase. In spite of the difference, "*late involvement of key project participants in GB processes"* and *"integrating environmental matters into the design in late phases of the GB project"* are the two highest scored secondary root causes for design and construction phases. On the other hand, *"lack of educated key project team members experienced in GB projects"* is the third secondary root cause for design, while *"lack of educated sub-contractors experienced in GB projects"* is the third root causes for construction. Hence, in order to minimize root causes experienced in design and construction phases of GB project delivery process, early involvement of key project team members, early integration of environmental aspects to the project, and integration of educated project team members experienced in GB projects and features are strongly suggested. Employing integrated project delivery (IPD) methods (Korkmaz et al., 2010b; Gultekin et al., 2013), integrated project team approach (Korkmaz et al., 2007; Beheiry et al., 2006), visualization tools (Korkmaz et al., 2010a) and document management tools (Stegall, 2004) will enable early involvement of project members and early integration of environmental aspects (Robichaud and Anantatmula, 2011).

The results of my study uncover waste and related root causes in GB projects and provide researchers to comprehend the essential requirements for the optimization of GB project delivery and successful completion of GB projects. These findings can be used for mitigating root causes and minimizing waste to decrease the hidden costs and to motivate owners to invest in GB projects. The results of this study enable researchers to determine the project delivery attributes which have a considerable impact on delivering the GB projects while enduring minimal time and cost-related waste. These findings can be used for developing models and/or tools for the owners that can proactively detect existing root causes and resulting waste in GB projects and aid them in the selection of appropriate credits from lists of credits within a GB rating system for achieving GB certification with minimal waste.

In following chapters (Chapter 3-4), these findings are used for developing a multi-attribute decision making support model as an integrated guideline for the owners and/or owners' representatives to determine appropriate and resource efficient GB certification credits that suit the particular attributes of project delivery the most.

References cited in this chapter:

Banawi, A.A. (2013) "Improving Construction Processes by Integrating Lean, Green, and Six-Sigma" PhD Dissertation. Department of Civil and Environmental Engineering. University of Pittsburgh.

Beheiry, S. M. A., Chong, W. K. and Has, C. T. (2006). "Examining the business impact of owner commitment to sustainability." *J. Constr. Eng. Manage.,* 132(4), 384-392.

Betts, M. and Lansley, P. (1993), "Construction Management and Economics: a review of the first ten years", *Construction Management and Economics,* 11(4), pp. 221–45.

Bon, R. and Hutchinson, K. (2000). "Sustainable construction: some economic challenges." *Building Research & Information*, 28(5-6), 310-314.

Brown, B. (1968). *A methodology used for the elicitation of opinions of experts*, The Rand Corporation, Santa Monica, Calif.

Cassidy, R., ed. (2003). "White paper on sustainability: a report on the green building movement" *Building Design & Construction.*

Chan, A. P. C., Scott, D. and Chan, A. P. L. (2004) "Factors affecting the success of a construction project*." J. Constr. Eng. Manage.,* 130(1), 153-155.

Dalkey, N.C. (1969). "*The Delphi method: an experimental study of Group opinion*", Santa Monica, CA: The RAND Corporation, 1-18.

Dalkey, N.C., Rourke, D.L., Lewis, R. and Synder, D. (1972). *Studies in the quality of life,* Lexington Books, Lexington, Mass., 55-83.

Eichholtz, P., Kok, K., and Quigley, J.M. (2013). "The economics of green building". *The Review of Economics and Statistics*, 95(1), 50-63.

Forbes, L.H. and Ahmed, S.M. (2011). *Modern Construction - Lean Project Delivery and Integrated Practices.* CRC Press, Taylor & Francis Group.

Glavinich, T.E. (2008). *Contractor's guide to green building construction*. John Wiley & Sons., New Jersey.

Gultekin, P., Mollaoglu-Korkmaz, S., Riley, D., and Leicht, R. (2013). "Process Indicators to Track Effectiveness of High-Performance Green Building Projects." *J. Constr. Eng. Manage.*, 139(12).

Gunhan, S. and Arditi, D. (2005a). "Factors affecting international construction." *J. Constr. Eng. Manage.*, 131(3), 273-282.

Gunhan, S. and Arditi, D. (2005b). “International expansion decision for construction companies.” *J. Constr. Eng. Manage.*, 131(8), 928-397.

Hakkinen, T. and Belloni, K. (2011) “Barriers and drivers for sustainable building”. *Building Research and Information*, 39(3), 239-255.

Hall, M. and Purchase, D. (2006). “Building or bodging? Attitudes to sustainability in UK public sector housing construction development.*“Sustainable Development*, 14(3), 205-218.

Hallowell, M.R. and Gambatese, J.A. (2010). “Qualitative research: application of the Delphi method to CEM research*.” J. Constr. Eng. Manage.*, 136(1): 99-107.

Hasson, F. and Keeney, S. (2011). “Enhancing rigour in the Delphi technique research.” *Technological Forecasting &Social Change,* 78(9), 1695-1704.

Horman, M.J.,Riley, D.R., Lapinsky, A.R., Korkmaz, S., Pulaski, M.H., Magent, C.S., Luo, Y., Harding, N. and Dahl, P.K. (2006). “Delivering green buildings: process improvements for sustainable construction.” *J. of Green Building* 1(1), 123-140.

Horman, M.J., Riley, D.R., Pulaski, M. H., and Leyenmeyer, C. (2004).”Lean and green: Integrating sustainability and lean construction.” *CIB World Congress*, Toronto, Rotterdam, The Netherlands,

Huovila, P. and Koskela, L. (1998). “The contribution of the principles of Lean Construction to meet the challenges of sustainable development." *Proc. of IGLC-6th*, Guaruja, Brazil.

Hwang, B.G. and Ng, W.J. (2013).”Project management knowledge and skills for green construction: Overcoming barriers.” *Int . J. of Project Manage.*, 31(2), 272-284.

Hwang, B.G. and Tan, J.S. (2010). “Green Building Project Management: Obstacles and Solutions for sustainable development,” *Sustainable Development*, 20(5), 335-349.

Jarrah, R. T. and Siddiqui, M. K. (2012). “Sustainability: Opportunities and challenges from a construction contractor’s perspective.” *ICSDEC 2012*, pp. 601-608.

Josephson, P.E. (2003). “Defects and defect costs in construction – a study of seven building projects in Sweden.” Department of Management of Construction and Facilities, Chalmers University of Technology, SE-41296, Goteborg, Sweden.

Kats, G., Alevantis, L. Berman, A., Mills, E. and Perlman, J. (2003). “The costs and financial benefits of Green Buildings.” *Rep. Prepared for California’s Sustainable Building Task Force,* Sacramento, CA.

Kibert, C.J. (2007). “The next generation of sustainable construction.” *Building Research & Information*, 35(6), 595-601.

Korkmaz, S., Messner, J., Riley, D.R. and Magent, C. (2010a).”High performance green building design process modeling and integrated use of visualization tools.” *J. Archit. Eng.,* 16(1), 37-45.

Korkmaz, S., Riley, D. and Horman, M. (2010b). “Piloting evaluation metrics for sustainable high-performance building project delivery*.” J. Constr. Eng. Manage.*, 136(8), 877-885.

Korkmaz S., Riley, D., and Horman, M. (2007). “Effective indictors for high performance green building delivery.” *Proc., ASCE-CIB Proc. of the 2007 Construction Research Congress*, ASCE, Reston,Va.

Koskela, L. (1992). Application of the new production philosophy to construction. *CIFE Technical Report,* No.72, Center for Integrated Facility Engineering, Dept. of Civil Engineering, Stanford University, Stanford, Calif.

Lai, I. K. W and Lam, F. K. (2010).“Perception of various performance criteria by stakeholders in the construction sector in Hong Kong.” *Constr. Manage. and Eco.*, 28(4), 377-391.

Lam, P. T. I., Chan, E. H. W., Chau, C. K., Poon, C. S. and Chun, K. P. (2009).”Integrating green specifications in construction and overcoming barriers in their use.” *J. Prof. Issues Eng. Educ. Pract.*, 135(4), 142-152.

Lapinsky, A.R., Horman, M.J. and Riley D.R. (2005). “Delivering sustainability: lean principles for green projects.” *ASCE Constr. Research Congress*, San Diego, CA, 27-31.

Lapinsky, A.R., Horman, M.J. and Riley D.R. (2006). “Lean processes for sustainable project delivery*.” J. Constr. Eng. Manage,* 132(10), 1083-1091.

Liker, J. K. and Meier, D. (2006). *The Toyota Way Field Book, a practical Guide for implementing Toyota’s 4Ps*. McGraw-Hill. New York, 17-37.

Linstone, H. A., and Turoff, M. (Eds.). (1975). *The Delphi method: Techniques and applications.* Reading, MA: Addison-Wesley Publishing Company.

Magent, C., Riley, D. and Horman, M. (2005). High performance building design processmodel, *ASCE Construction Research Congress*, April 5-7, San Diego, CA, 424-428.

Mapp, C., Nobe, M. E. E. and Dunbar, B. (2011). “The Cost of LEED-an analysis of the construction costs of LEED and non-LEED banks”, *JOSRE,* vol. 3(1), 254-273.

Marphi. J. (2014). “Managing green building projects.” World Green Building Council Europe Regional Network. Presented for Turkish Green Building Council, March 10, 2014.

McGraw-Hill Construction (2006). *Green building smart market report: Design & construction intelligence,* New York.

Meryman, H. and Silman, R. (2004). “Sustainable engineering - Using specifications to make it happen.” *Struct. Eng. Int. (IABSE, Zurich, Switzerland),* 14(3), 216-219.

Mitchell, V.W. (1991). “The Delphi technique: An exposition and application.” *Tech. Anal. Strat. Manage.*, 3(4), 333-358.

Mogge, J. (2004). “Breaking through the 1st cost barriers of sustainable planning, design and construction.” PhD Diss., Georgia Institute of Technology, Atlanta, GA.

Molenaar,K. R., Sobin, N., and Anrillón, E. (2010). “A synthesis of best-value procurement practices for sustainable design-build projects in the public sector.” *J. Green Build.,* 5(4), 148-157.

Nahmens, I. (2009). “From lean to green construction: a natural extension.” *Proc. of ASCE Construction Research Congress (CRC),*1058-1067.

Nilson, M. L. (2005). “Quantifying the cost impacts of LEED-NC Gold Constuction in New York City.” Senior Honor Thesis. Department of Civil and Environmental Engineering, Lafayette College..

Ofori, G. and Kien, H. L. (2004). “Translating Singapore architects’ environmental awareness into decision making.” *Build. Res. Inf.,* 32(1), 27-37.

Okoli C. and Pwalowski, S.D. (2004). “The Delphi Method as a research tool: an example, design considerations and applications.” *Information & Management,* 42(1), 15-29.

Pearce, A. R. and Vanegas, J. A. (2002). “A parametric review of the built environment sustainability literature.“ *Int. J. Environ. Technol. Manage*., 2(1-3), 54-93.

Porter, M. and van der Linde, *C.* (1995).*Green and competitive*. Harvard Business Review, 119-134.

Pulaski, M., Pohlman, T., Horman, M. and Riley, D.R. (2003). “Synergies between sustainable design and constructability at the Pentagon.” *Proc. of ASCE CRC,* 1-8.

Riley, D (2009). Personal Conversation Regarding Master’s Thesis Conclusion. Pennsylvania State University, Engineering Units. 2 April 2009.

Riley, D. and Horman, M. (2005). “Delivering green buildings: High performance processes for high performance projects.” *Proc., Engineering Sustainability 2005: Conf. of the Mascaro Sustainability Initiative.*

Riley, D., Magent, M. and Horman, M. (2004). “Sustainable metrics: a design process model for high performance buildings.” *Proc. CIB World Building Congress* Toronto, CA.

Riley, D., Pexton, K and Drilling, J. (2003). ”Procurement of sustainable construction services in the United States: the contractor’s role in green buildings.” *UNEP Industry and Environment,* April-Sep., 66-73.

Riley, D. R., Varadan, P. James, J. S., and Thomas, H. R. (2005). “Benefit-cost metrics for design coordination of mechanical, electrical, and plumbing systems in multistory buildings.” *J. Constr. Eng. Manage.,* 131(8), 877-889.

Robichaud, L.B. and Anantatmula, V. (2011). “Greening project management practices for sustainable construction”. *J. of Manage. Eng.*, 27(1), 48-57.

Rowe, G., Wright, G. and Bolger, F. (1991). “Delphi: A reevaluation of research and theory.” *Technological Forecasting and Social Change,* 39(3), 235-251.

Shrestha, P.P. and Pushpala, N. (2012). “Green and non-green school buildings: an empirical comparison of construction cost and sustainability.” *Proc. ASCE CRC,* 1820-1829.

Simonsson, P., Björnfot, A., Erikshammar, J. and Olofsson, T. (2012). “’Learning to see’ the effects of improved workflow in civil engineering projects.” *Lean Constr. J.,* 35-48.

Smith, A. (2003). "Building momentum: National trends and prospects for high performance green buildings." *Rep. Prepared for the U.S. Senate Committee on Environment and Public Works*, USGBC, Washington, D.C.

Sprau, T. (2009) "Developing the Basis for Process Metrics for Sustainable Building Performance". M.S. Thesis. Department of Architectural Engineering. The Pennsylvania State University.

Stegall, N. (2004). "Cost implications of LEED Silver Certification for new house residence at Carnegie Mellon University".Senior Honors Research Project, Carnegie Inst. of Tech.

Swarup, L., Korkmaz, S. and Riley, D. (2011). "Project delivery metrics for susteianble, high performance buildings." *J. Constr. Eng. Manage.*, 137(12), 1043-1051.

Syal, M.G., Mago, S. and Moody, D. (2007). "Impact of LEED-NC credits on contractors". *J. Archit. Eng.*, 13(4), 174-179.

Tagaza, E. and Wilson, J.L. (2004). "Green buildings: drivers and barriers - lessons learned from five Melbourne developments." *Report Prepared for Building Commission by University of Melbourne and Business Outlook and Evaluation*.

Turner Construction Company (2012). "*Green building market barometer.*" <http://www.turnerconstruction.com/about-us/sustainability/green-market-barometer> (accessed Ap. 21, 2014).

USGBC (2009). U.S. Green Building Council. "LEED 2009 for New Construction and Major Renovations Rating System." <http://www.usgbc.org/resources/list/study-guides >, (accessed Feb.10,2014).

Vidal, L.A., Marle, F. and Bocquet, J.C. (2011). "Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects." *Expert Systems with Applications*, 38(2011) 5388-5405.

Wiley, J.A., Benefield, J.D., and Johnson, K.H.(2010)."Green design and the market for commercial office space." *Journal of Real Estate Finance and Economics*, 41(2), 228-243.

Williams K. and Dair C. (2007) "A framework of sustainable behaviors that can be enabled through the design of neighborhood-scale developments." *Sustainable Development*, 15(3),160-173.

Womack, J.P. and Jones, D.T. (1996). *Lean Thinking: Banish waste and create wealth in your corporation.* New York, NY: Free Press, Simon&Schuster, Inc., 1996, Second Edition, 2003.

Wu P. and Low S.P. (2010). "Project management and green buildings: lessons from rating systems." *J. Prof. Issues Eng. Educ. Pract.*, 136(2), 64-70.

Zhang, X.L., Shen, L.Y., Wu, Y.Z. (2011). "Green strategy for gaining competitive advantage in housing development: a China study." *J. of Cleaner Production*, 19(1), 157-167.

CHAPTER 3

DELPHI METHOD BASED WEIGHT ASSIGNMENT APPROACH FOR DESIGNATING RELATIVE WEIGHTS TO GREEN BUILDING PROJECT DELİVERY ATTRIBUTES

3.1 Introduction

As discussed in the previous chapter (Chapter 2), primary and secondary root causes leading to waste in terms of time increase and cost overruns are associated with project and team related GB project delivery attributes, particularly project team related attributes. “Project delivery attributes” or “process indicators” (e.g. qualification of project teams, timing of project teams’ involvement, project delivery methods) are described as the variables in GB project delivery (Korkmaz et al., 2007).

Previous studies manifest that project delivery attributes have considerable influence on the project success in terms of time, cost and, recently, sustainability (Korkmaz, 2007; Sprau, 2009; Korkmaz et al., 2010; Swarup et al., 2011; Gultekin et al., 2013). In fact, project delivery attributes either facilitate or resist the success of the project (Lim and Mohammed, 1999). A project can only be defined as a successful project when it is completed on time and within budget while ensuring an acceptable profit margin and satisfying expectations (Wuellner, 1990). Thus, considering project delivery attributes is an essential requirement for obtaining better outcomes and ensuring successful completion of GB projects, (Korkmaz et al., 2007; Korkmaz et al., 2010).

When the waste types and related primary and secondary root causes in GB project delivery process were examined in depth, it is clear that “*timing of project teams’ involvement”, “timing of environmental matters’ integration”* and “*qualification of project teams*” are the three crucial GB project delivery attributes which crucially affect on enduring minimal waste throughout GB project delivery process and ensuring successful completion of GB projects (see Table 2.5-6 in Chapter 2).

As the results of the previous chapter (Chapter 2) illustrated, if the project team related GB project delivery attributes are not sufficient to fulfill the specific requirements of GB projects, high levels of time and cost related waste could be generated, hence leading to increased levels of hidden costs. Particularly, if the owner intends to achieve GB certification and if the existing project team related attributes of project delivery are not adequate for meeting the specific requirements of the GB certification credits selected and the GB rating system followed, increased levels of time, money and labor could get wasted throughout the phases of GB project delivery process (Sprau, 2009; Wu and Low, 2010; Robichaud and Anantatmula, 2011; Banawi, 2013; Gultekin et al., 2013). In order prevent this challenge, a decision making support model is needed to be developed to provide guidance in the selection of the GB certification credits in compliance with the particular GB project delivery attributes. However, such a decision making model as a guideline is still missing in the GB industry and literature even though it is a crucial necessity for the optimization of GB project delivery and completion of GB projects with successful outcomes in terms of time, cost and sustainability.

In order to fulfill this gap, I aim at developing an interconnected decision making support model to determine appropriate credits that suit the particular attributes of GB project delivery the most. On the road of developing my proposed decision making support model, I focus on "*timing of project teams' involvement in GB processes"* and "*qualifications (i.e. experience and education) of project teams in GB projects and features"*. In this study, *timing of project teams' involvement* also implies *timing of environmental matters' integration,* since integrating Green features into the projects is closely related to *timing of project teams' involvement* as explained in Chapter 2.

According to the reasoning mechanism of multi-attribute modeling, it is necessary to first set a hierarchical framework based on the GB project delivery attributes, and second assign relative weights to these hierarchically designed attributes (Triantaphyllou, 2000). With the aim of meeting these requirements, this chapter addresses the issues of (1) *building a hierarchical framework* based on the GB project delivery attributes which is to be developed into an integrated decision making support model, (2) *designating importance levels to these hierarchically designed GB project delivery attributes* by using this hierarchical framework in which credits under LEED® NC Rating System was integrated, and (3) *assigning relative weights to these hierarchical attributes* based on their importance levels.

This chapter presents the first part of my envisioned decision making support model that employs Delphi Method based weight assignment approach to assign relative weights to the hierarchically designed GB project delivery attributes. These relative weights are inputted into the multi-attribute decision making method (i.e. TOPSIS) which is engaged in the second part of this integrated model (see Chapter 4) to determine appropriate GB certification credits that comply with the particular attributes of GB project delivery. In this weight assignment approach, Delphi Method is used as the main method for ascertaining importance levels to hierarchically designed GB project delivery attributes via expert opinion, while TDR Method is utilized as a conjunctive method to designate relative weights to the attributes by normalizing the importance levels. Normalization allows researchers to derive relative weights, whose sum should be equal to one thereby; the relative weights can be inputted into the decision making method as constant numbers. It is expected that Delphi Method based weight assignment approach appoint relative weights to hierarchically designed attributes with high sensitivity and reliability, since Delphi Method provides increased data quality and reliability by combining several experts' judgments and eliminating ambiguities and inconsistencies. Engages such an integrated methodology provides for examining the relative importance levels of project delivery attributes in a holistic perspective. My research employs this integrated approach to address the need for developing a multi-attribute decision making model that accommodates weighted analysis of importance levels for GB project delivery attributes. In fact, establishing a weighted list of importance levels for GB project delivery attributes still remains to help for optimizing GB project delivery and ensuring successful project outcomes (Cha and O'connor, 2005; Korkmaz et al., 2010; Gultekin et al., 2013).

3.2 Research Methodology

This research is driven by a multi-methodological approach combined with qualitative and quantitative research methods (Yin, 2003). This chapter is conducted in four stages to constitute the reasoning mechanism of this integrated approach: (1) reviewing literature, (2) building the hierarchical framework, (3) performing the Delphi Method, (4) combining Delphi Method and TDR Method. The Delphi Method is the main research method employed to achieve research objectives stated within the content of this chapter. The research methodology of this study described in this chapter is presented via IDEF0 modeling language by employing the input-activity-output relation (see Fig.3.1).

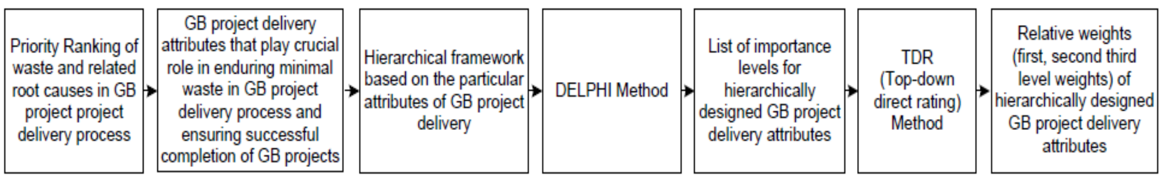

Fig 3.1: Delphi Method based weight assignment research methodology

A broad literature review was performed to investigate existing qualitative and quantitative research methods used for weight assignments and to ascertain the particular GB project delivery attributes for setting the hierarchical framework. The limitations and advantages of these research methods were analyzed to determine the most suitable method for eliciting relative weights. Drawing from my findings of the previous chapter (Chapter 2) and literature review, I built a three tiered framework based on two particular attributes of GB project delivery. Fifty four credits categorized under LEED® 2009 NC Rating System were integrated in this hierarchical framework to be utilized (1) in the Delphi Method based weight assignment process to assign relative weights to the GB project delivery attributes, and (2) in multi-attribute decision making process (i.e. TOPSIS) to determine appropriate and resource efficient credits among these fifty credits in accordance with the GB project delivery attributes.

After building the hierarchical framework, Delphi Method based weight assignment approach was performed to appoint relative weights to the hierarchically designed GB project delivery attributes. With the intention to designate importance levels to the hierarchically designed GB project delivery attributes, a two-rounded

Delphi Method was firstly engaged on a panel of eleven highly qualified panel members (i.e. GB consultants, academics, professionals). In order to assign the first, second and third level relative weights for hierarchical attributes, TDR Method was secondly employed by using importance levels of attributes attained by Delphi Method. TDR was applied on these importance levels to assign relative weights by normalizing vast amount of data gathered from the Delphi Inquiry into smaller and less redundant data. This strategy will provide researchers derive reliable and sensitive relative weights, whose sum should be equal to one; thereby, these relative weights can be later used as inputs in the multi-attribute methods (i.e. TOPSIS).

3.3 Green Building Project Delivery Attributes

Dealing with complexities in GB projects (i.e. technical difficulties, time and cost impacts) require detailed analysis of the project delivery process considering all the different project participants (i.e. consultants, sub-contractors, suppliers) (Robichaud and Anantatmula, 2011). However, the difficulties encountered while applying GB certification credits, responding to the unique requirements of GB projects (e.g. detailed documentation) can potentially cause high waste associated with *limited qualifications* and *late involvement* of project teams which in return impact the GB projects as additional time, cost and labor requirements (Sprau, 2009; Hwang and Tan, 2010; Robichaud and Anantatmula, 2011; Hwang and Ng, 2013; Gultekin et al., 2013).

Many of the previous studies uncovered during the literature review highlight "*qualification (i.e. experience and educations/knowledge) of project teams in GB projects and features"* and "*timing of involvement in GB project delivery process"* as the most critical factors affecting the overall success of GB projects. Some of these studies investigate the required skills, knowledge and practices in order to deal with escalating complexities at GB projects certifications (Syal et al., 2007; Wu and Low, 2010; Robichaud and Anantatmula, 2011; Hwang and Ng, 2013). Some of them focus on early involvement of project teams in the process of GB project delivery (Riley and Horman, 2005; Riley et al., 2005; Beheiry et al., 2006; Molenaar et al., 2010; Swarup et al., 2011).

Even though all these studies emphasized the importance of project delivery attributes to ensure successful project outcomes, none of these studies addressed the necessity for examining the timing of project teams' involvement or the qualification of project teams in terms of their relative importance for achieving GB certification under a hierarchical framework based on project team (IP) approach. In fact, IP team approach has been emphasized by previous studies that aim to fulfill the project's particular qualification and service requirements (Mapp et al., 2011). Study conducted by Gultekin et al. (2013), on the other hand, addresses the importance levels for sustainable project performance outcomes (e.g. owner's vision statement), but omit to examine these attributes in detail under the light of a hierarchical framework considering multiple project teams. However, project team members or project participants (e.g. PM, contractors, suppliers, subcontractors) are the key players of a project (Chua et al., 1999).

In the study conducted by Gultekin et al. (2013), the data was gathered via surveys including GB projects used in earlier studies and structured interviews. One of the important limitations indicated in this study is that the data was collected from different types of respondents (i.e. owner, architect and contractors) after the completion of investigated projects (Gultekin et al., 2013). More importantly, although Gultekin et al. (2013) addresses the green office buildings having LEED® certificate, the authors did not indicate any information regarding the respondents' GB expertise levels and USGBC accreditations. In fact, besides the types of respondents, their level of knowledge and expertise in LEED® Rating Systems and/or other GB rating systems also have great importance on the accuracy of the data collected. Particularly, in complex environmental systems, expert opinion is often the best accessible information as they have broad experience with the subject of profession (Krueger et al, 2012).

The study conducted by Gultekin et al. (2013) underlines the need for examining project delivery attributes by considering other types of buildings and the need for addressing in-depth analysis of certain case studies with the aim of supporting the successful delivery of GB projects. Gultekin et al. (2013) also suggests to examine project delivery attributes (i.e. knowledge base, expert knowledge) in different countries and geographies by focusing on their relative impact on the performance of the project.

My study explained in this chapter addresses the need to examine relative weights to *timing of involvement* and *qualification of project teams* which is analyzed with a hierarchical framework based on LEED® NC Rating System, that is developed through the use of Delphi Method based weight assignments approach conducted with GB experts accredited by US Green Building Council and/or UK Green Building Council. Designating relative weights to the project delivery attributes by using an integrated hierarchical framework that is structured under the light of LEED® NC Rating System will provide examination of these attributes' importance levels for each credit and designation of these attributes' relative weights in a holistic perspective.

Timing of project teams' involvement and qualification of project teams as the particular attributes of GB project delivery:

Timing of involvement and *qualifications (i.e. experience and education) of project teams* are characterized as independent variables that can have great influence on project outcomes (Korkmaz et al., 2007; Korkmaz et al., 2010).

Project teams' experience with the GB rating system (i.e. LEED) and regarding the credits is highlighted with the utmost importance in some studies since experience and costs (i.e soft costs) related to GB certification requirements (i.e. documentation) are suggested to be inversely proportional to each other (Mapp et al., 2011). Project team members, who are not fully equipped to fulfill the requirements of selected GB certification credits, propose a great risk of impacting the GB Projects with the increased cost and time endured (Sprau, 2009; Wu and Low, 2010; Robichaud and Anantatmula, 2011; Gultekin et al, 2013). On the contrary, a Project Manager who has solid experienced in GB projects, certified as LEED AP and familiar with related products in GB market and their application requirements would be able to easily manage GB Projects within the allowed budget and time (Robichaud and Anantatmula, 2011). Similarly, hiring an experienced MEP (Mechanical, Electrical and Plumbing) Teams in GBs allow minimizing 10% of the MEP construction costs (Cassidy, 2003).

The study conducted by Sprau (2009) shows that an experienced project team in GB features and related requirements would allow obtaining better project outcomes in terms of time, cost and sustainability. The reason is that they have a positive impact on the successful delivery of a GB project which seeks a LEED® certification. On the contrary, an inexperienced project team could cause to spend more time, cost and labor. Moreover, this inexperienced team could prevent the achievement of successful project outcomes in terms of sustainability (Sprau, 2009).

In addition to employing highly qualified project teams in GB projects, timing of involvement for those personnel is also another crucial factor that needs to be addressed to ensure successful completion of GB Projects and accomplishment of high level GB certification (Riley and Horman, 2005; Beheiry et al., 2006; Riley et al., 2005; Beheiry et al., 2006; Molenaar et al., 2010; Swarup et al., 2011; Gultekin et al., 2013). All project team members should make sure that they clearly understand the project objectives at the initial stages of the project and apply "Green" practices in every phase to guarantee the realization of GB certification goals (Bogenstätter, 2000). Timing of key project team involvement is also an essential element in the effort of building an integrated project team as the foundation for success of GB projects (Korkmaz et al., 2010; Swarup et al., 2011). Accordingly, early involvement of key project team members make greater impact on critical decisions (i.e. site selection, strategic planning and preliminary design) concerning GB projects (Robichaud and Anantatmula, 2011). Contrary, late involvement would create greater complexities for integrating the owners' project goals into the site selection, SD, opening budget and schedule forecasts which would effectively cause to increased levels of costs and time to complete GB Projects (Bogenstätter, 2000).

According to the extensive literature review, both *early involvement* and *higher qualifications* of project teams are the two critical drivers for developing valuable management strategies that would optimize GB project delivery process and prevent the project to incur additional time and expenditures (i.e. additional soft cost) (Wu and Low, 2010; Robichaud and Anantatmula, 2011; Hwang and Ng, 2013). Therefore, *timing of project teams' involvement* and *qualification of project teams in GB features* have a significant influence on minimizing wasteful activities throughout the GB project delivery process and achieving better project outcomes in terms of time, cost and sustainability (Sprau, 2009; Banawi, 2013).The findings from the literature review corroborate with my findings presented in the previous chapter (see Chapter 2). Based on these results, I built the hierarchical framework on "*qualification of project teams in GB projects and features*" and "*timing of project teams' involvement in GB processes*".

3.4 Hierarchical Framework based on Green Building Project Delivery Attributes

This hierarchical framework was set to assign relative weights to the project delivery attributes that is developed in next chapter into a multi-attribute decision making support model to determine appropriate credits to be efficiently fulfilled by the particular attributes of GB project delivery (project and project team related) for GB certification. This hierarchical framework is presented in Figure 3.2.

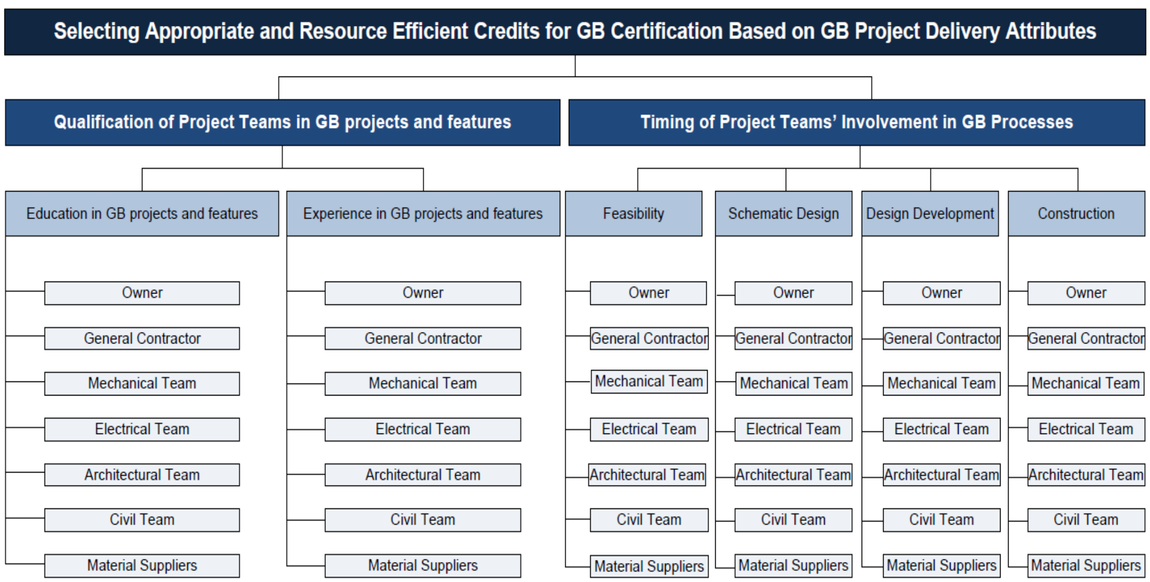

Fig 3.2: Hierarchical framework based on GB project delivery attributes

"*Qualification in GB projects and features*" and "*timing of involvement in GB project delivery process*" are indicated to be the major attributes; therefore, located at the first level of this hierarchical framework. Each of these primary attributes is divided into sub-attributes located on the second level.

"*Qualification of project teams in GB projects and features*" part is classified into two secondary attributes which are (1) *experience*, and (2) *education/knowledge*.

Experience refers to the years of experience in GB projects which is required for analyzing practical information. Education/knowledge refers to accreditation by a widely-accepted GB council (i.e. US Green Building Council, UK Green Building Council), and/or having Professional degrees (i.e. Professional Engineer (PE), Building Engineering Modeling Professional (BEMP)) relating to the AEC (Architecture / Engineering / Construction) industry, and/or having Bachelor, M.Sc (Master of Science) and PhD (Doctorate of Philosophy) degrees relating to the AEC industry which are required for analyzing academic information regarding the GBs.

"Timing of project teams' involvement in GB processes" part is divided into four secondary attributes which are *(1) Feasibility, (2) Schematic Design (SD), (3) Design Development (DD), and (4) Construction (CA).* In this framework, Feasibility Phase includes project feasibility, initiation and mobilization. Schematic Design (SD) Phase includes project planning, preliminary design, and material selection. Design Development (DD) Phase consists of design development and construction documentation (CD). Construction Phase refers to Construction Administration (CA) and the implementation on site.

In this study, *"timing of project teams' involvement in GB processes"* is designed considering specifically for a Design-Build project. Design-Build Method (DB) which is an integrated project delivery (IPD) procedure is strongly recommended project teams to ensure the successful completion of GB projects (Korkmaz et al., 2010). However, in order to apply this framework on a fast-track project, the timing of project teams' involvement part should be redesigned to cover for the project lifecycle as a whole rather than dividing it up into different phases in which "timing of involvement" would be identified as percentages in terms of the total project duration. In that case, "timing of involvement " part would be considered in terms of the percentage progression of the whole project.

IPD procedure necessitates building integrated project teams which is suggested as the most significant instrument for the success of GB project delivery (Korkmaz et al., 2010; Robichaud and Anantatmula, 2011; USGBC, 2009). Based on the

IP team approach, "*project teams"* part is introduced into the framework as the third level attribute. *Project teams*, listed under every secondary attribute, are divided into seven groups: owner, general contractor (GC), architectural team (AT), mechanical team (MT), electrical team (ET), civil team (CT), and material suppliers (MS). In this manner, this three tiered framework ensures that relative weight of each project team (third level weights) are derived within every secondary attributes including Experience, Education, Feasibility, Schematic Design, Design Development, and Construction, respectively.

This framework including a broad range of project teams from different technical disciplines encourages interdisciplinary synergies (NCI, 2007). In fact, different parties getting involved in a construction project provide team effort which is a critical factor for the successful completion of the project (Chan et al., 2004). It is expected that this advanced framework will be utilized in future studies whose goal is to develop multi-attribute models and/or tools for owners to provide aid in developing tools and/or models for providing help in the pursuit of successful GB projects.

With the intention to assign relative weights to these hierarchically designed project delivery attributes, LEED® 2009 NC under BD+C (Building Design and Construction) Rating System was selected to integrate into this hierarchical framework. I selected LEED®, because this GB certification program is widely accepted and used all over the world (Syal et al., 2007; Shrestha et al., 2012; Gultekin et al., 2013); despite, some hesitations still remain due to possible higher costs, longer time and elevated levels of technical difficulties inflicted on the GB projects (Turner, 2012).

Among all the credits listed under LEED® 2009 NC, total of fifty four credits that correspond to 100 base points were integrated into the hierarchical framework excluding the ten-points corresponding to the bonus credits listed under "regional priorities" and "innovation in design" categories. Credits integrated into the hierarchical framework are listed under the main categories of LEED® 2009 NC BD+C Rating System.

Integration of credits under a GB rating system provides designation of these attributes' relative weights in a comprehensive perspective. Additionally, integration of

GB certification credits into the hierarchical framework ensures that this highly structured framework can be further developed into a multi-attribute decision making support model to determine appropriate and resource efficient GB certification credits which suit particular attributes of GB project delivery the most.

3.5 Delphi Method-based Weight Assignment Approach

Assignment of weights (w_{ij}) can be described as "*the assessment of preference structure*" representing subjective insights of the decision makers (DMs) (i.e. policy makers) (Nijkamp et al., 1990). Weight assignment procedures and related research methods used for determining reliable values to represent the relative importance of DMs' preferences are crucial factors in the multi-attribute analysis. For this reason, weights should be determined with high sensitivity and reliability (Nijkamp et al., 1990; Weber and Borcherding, 1993). Depending on this essential criterion, I built a highly structured weight assignment approach to assign relative weights to the hierarchical project delivery attributes afore mentioned. With the intention to (1) increase the reliability and sensitivity of the weight assignment process, (2) support internal consistency and (3) decrease vulnerabilities in data, Delphi Method was employed as the main method to assign relative weights to the hierarchically designed attributes (Dalkey et al., 1972; Hasson and Keeney, 2011).

Delphi Method as a problem oriented mapping method aims at developing and weighting hierarchical goals and objectives, and evaluating hypothetical facility alternatives (Linstone and Turoff, 1975). This carefully planned method obtains rational judgments from a preselected group of experts through series of questionnaires (Brown, 1968). The goal of using Delphi method in this research is to designate (1) the levels of importance to the tertiary attributes for every credit in LEED® 2009 NC by considering in particular, and (2) the levels of importance to the secondary and primary attributes for the requirements of LEED® 2009 NC by considering in general.

The reasons for employing Delphi Method as the central step to this weight elicitation approach are as follows: (1) Expert opinion is often the best accessible information regarding complex environmental systems since an expert is likely to be the person who has comprehensive experience relevant to the subject of interest/profession (Krueger et al, 2012). Delphi Method, as an expert-oriented method, allow assigning the relative weights and the importance levels of GB project delivery attributes with high accuracy by using the three tiered framework in which 54 credits in LEED® 2009 NC were integrated. (2) Delphi Method is flexible and easy applicable method which enable the panel members to be involved with the process regardless of their geographic and/or time constraints (Gunhan and Arditi, 2005a,b; Geist, 2010). This feature of Delphi Method provides that GB experts attended this time consuming and laborious inquiry by arranging their limited time to their conveniences. (3) Delphi method, based on iterative rounds, allow higher reliability and quality in outputs by performing interactive rounds and providing controlled feedbacks (Mitchell, 1991; Rowe et al., 1991). This feature of Delphi Method provides that outputs from this structured qualitative procedure does not need to be test-retested to control the reliability of data (Okoli and Pawlowski, 2004; Hasson and Keeney, 2011). (4) Delphi method is highly effective for decreasing biases in data and providing trustworthy outputs, and thereby promotes designation of sensitive and reliable levels of importance to the GB project delivery attributes (Curtis, 2004; Gunhan and Arditi, 2005a, b). For these underlined reasons, Delphi Inquiry, as a useful instrument engaged the intelligence of experts, held with high regards in the literature to strengthen the weight assignment procedure and to assure researchers derive reliable and sensitive relative weights (Emory and Cooper, 1991, Hilbert et al., 2009; Gunhan and Arditi, 2005a). Tasks involved in this Delphi Process are presented in Fig 3.3.

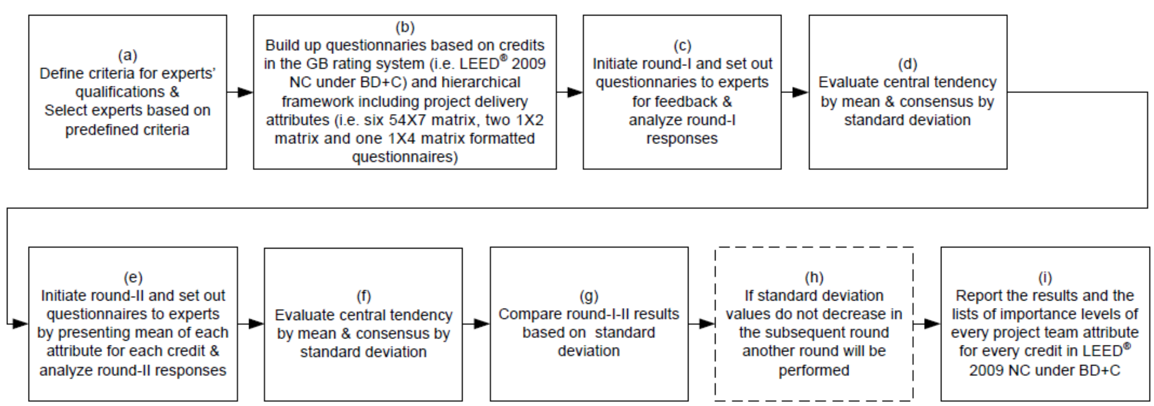

Fig 3.3: Tasks involved in the Delphi Process for designating importance levels to GB project delivery attributes

The first step of the Delphi Method is to define the criteria for experts' qualifications to ensure that they have sufficient knowledge and experience in the GBs and GB certification (i.e LEED® 2009 NC) (Hallowell and Gambatese, 2010) (Fig. 3a). It was expected that experts meet at least one criterion from each of the following two groups: (1) knowledge/education level, (2) experience level. Criteria for *knowledge/education* level are: (1.1) to be at least a LEED® Green Associate (LEED GA), and/or BREEAM® (Building Research Establishment Environmental Assessment Methodology) International Assessor, (1.2) to have education degree (at least M.Sc. or M.Arch. or M.Eng.) related to AEC industry, (1.3) to have professional degree in their subjects, such as Building Engineering Modeling Professional (BEMP), Commissioning Process Management Professional (CPMP), Project Management Professional (PMP) or Professional Engineer (PE). Criteria for *experience* level are: (2.1) at least two years of professional experience in GBs seeking LEED® Certification and/or BREEAM® Certification, (2.2) at least five years professional experience in AEC industry, (2.3) at least two years professional experience in ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) standards and applications. Selecting panel participants based on the predefined qualification criteria provides that all panel members involved in this Delphi Process have sufficient knowledge and experience in the GBs and GB certification. Panel participants with sufficient knowledge and experience in the GBs and GB certification provide data accuracy, data quality and data reliability, as well.

Eleven panel members were selected based on these predefined criteria; some of these panel participants are GB consultants, some of them are academics (i.e. Prof. and Asst. Prof.) and some are professionals in the AEC industry (e.g., project manager). Selection of panel participants from different disciplines not only ensures multiplicity in the outputs but also helps combine experiences and knowledge of different professional fields. Qualifications of these panel members participated in this Delphi Inquiry can be found in Table 3.1 (Fig. 3.3a).

Table 3.1: Panel members participating in Delphi process for designating importance levels to hierarchical GB project delivery attributes

Profession	Experience (year) in Construct. Ind.	Experience (year) in GBs	Education Degree	Professional Degree related to Profession Discipline	Professional Degree related to GB Rating System	
Industrial Engineer / GB Consultant	≥10	5-10	M.Sc.	BEMP, CPMP	LEED AP	BREEAM Int. Asses.
Civil Engineer / GB Consultant	>10	5-10	M.Sc.	PMP	LEED AP	BREEAM Int. Asses.
Mechanical Eng. / GB Consultant	>10	>10	Bachelor	PE, CCP	LEED AP	-
Architect	>10	5-10	PhD	Prof.	-	-
Architect / GB Consultant	5-10	5-10	PhD	Assoc. Prof.	-	BREEAM Int. Asses.
Architect / GB Consultant	>10	5-10	M.Arch.	-	LEED AP -	-
Civil Engineer / Project Manager	>10	5-10	M.Sc.	-	LEED AP	-
Mechanical Engineer / GB and Project Management Consultant	5-10	5-10	M.Sc.	PMP	LEED AP	-
Civil Engineer / GB and NGB Project Planning	5-10	2-5	MBA	-	LEED AP	-
Civil Engineer	5-10	2-5	PhD candidate	-	LEED GA	-
Architect	5-10	2-5	M.Arch.	-	LEED GA	-

The second step is to create questionnaires to be used in Delphi Process that builds on the hierarchical framework (Fig. 3.3b). Nine questionnaires, based on the hierarchical framework, were built to be used in the Delphi Inquiry. Six types of them were prepared for designating importance levels to every project team (in the third level of the hierarchical framework) under each of six secondary attribute. Each of six questionnaires, which include fifty four GB certification credits, was particularly built to designate importance levels to every project teams for each of six secondary attribute. These six questionnaires provide panel members assign importance levels to each of seven project teams (tertiary attribute) within the context of every secondary attributes (Experience, Education, Feasibility, Schematic Design, Design Development, and Construction.), respectively. Additionally, two different questionnaires were prepared for designating importance levels to secondary attributes. One of these two questionnaires was built for secondary attributes under “qualification of project teams”, which includes Experience, Education. The other questionnaire was built for secondary attributes under “timing of project teams’ involvement”, which includes Feasibility, Schematic Design, Design Development, and Construction. These two questionnaires provide panel members appoint importance levels to six secondary attributes by comparing each other. Furthermore, one questionnaire was built for assigning importance levels to the primary attributes, which are “qualification of project teams” and “timing of project teams’ involvement”. This questionnaire provides panel members designate importance levels to the primary attributes by comparing each other.

In this manner, nine types of questionnaires were totally distributed to eleven panel members (DMs) qualified in GB practices via e-mail in two rounds. Two-rounded process was employed since it is strongly suggested to obtain more accurate outputs (Dalkey et al., 1972) (Figure 3.3 c). In this method, panel members were asked to give points to each project teams in terms of their importance levels for fulfilling each credit (i.e. 54 credits) under LEED® 2009 NC within each of secondary attribute (i.e. 6 numbers of 54X7 matrix formatted questionnaires). Additionally, panel participants were asked to give points to secondary and primary attributes in terms of the importance levels for meeting the requirements of LEED® Certification and regarding the process. Nine-point scale was employed as the grading system at which; “1” indicates “without any importance” while “9” corresponds to “extreme importance”. Each of the GB experts was asked to give total of 2276 points to nine types of questionnaires in each round. Tertiary attributes (third level attributes) representing project teams were analyzed by six different 54X7 matrix questionnaires. The larger amounts of data gathered from six types of 54X7 matrix formatted questionnaires that aim at examining the levels of importance for project teams (tertiary attributes) in terms of the 54 credits listed under LEED® 2009 NC within each of secondary attribute. Secondary -attributes were analyzed by 1X2 and 1X4 matrix formatted questionnaires within this two-rounded Delphi Method. Primary attributes were examined by 1X2 matrix formatted questionnaire throughout this process.

Panel participants were given considerable time (four to six weeks) to fill out these nine different questionnaires since completing each questionnaire is a detail-oriented and time consuming activity. Carefully selecting panel members and allowing enough time for them to provide feedbacks for this compelling Delphi Method will enable to overcome possible inaccuracies and confusions due to large amounts of data needed to be processed and allow the achievement of more reliable and quality outputs from highly qualified eleven panel participants.

In order to represent feedbacks, mean or median values should be integrated into the process for analyzing the rationales of the panel members in subsequent rounds (Fig 3.3d) (Rowe and Wright, 2001; Linstone and Turoff, 1975; Hallowell and Gambatese, 2010). In the literature, some of the studies prefer to use mean values to derive results from the feedbacks (Linstone and Turoff, 1975; Curtis, 2004; Hahs-Vaughn, 2005; Chu and Hwang, 2008; Markmann et al., 2013; Chen et al., 2013) while some of them use median to derive results (Gunhan and Arditi, 2005a; Geist, 2010). Among the number of studies analyzed during the literature review; three among eight studies used interquartile range (IQR) to describe the consensus (Linstone and Turoff, 1975; Chu and Hwang, 2008; Geist, 2010), while all the other five studies used standard deviation (SD) (σ) (Gunhan and Arditi, 2005a; Hahs-Vaughn, 2005; Markmann et al., 2013; Chen et al., 2013; Curtis, 2004).

Statistical group response consists of quantitative feedback such as median and IQR, or mean value and SD based on numerical ratings of each item (Geist, 2010). Mean value was calculated to determine the central tendency of all feedbacks since mean values is a widely-used compared to median value. As previous studies suggested, SD was used for representing the group consensus because mean and SD are interrelated values. In this way, mean value and SD were calculated for each importance levels of primary (i.e. qualification and timing of involvement), secondary (i.e. experience, education, feasibility, SD, DD, CA) and tertiary attributes (i.e. seven project teams) based on the scores given by eleven experts.

After completing the first round of surveys, the second round was performed since two-rounded Delphi process is strongly suggested to achieve more specific consensus among panel participants by comparing results from subsequent rounds (Dalkey et al., 1972). In each round performed after the first round, questionnaires are distributed to represent mean values to the panel members for re-evaluation and for reaching a consensus among them. Second round of Delphi inquiry was executed with the same eleven panel participants for which nine questionnaires were distributed based on the hierarchical framework by representing the mean values from first round (Fig 3.3 e). Similar to the first round, panel members had four to six weeks to re-evaluate the questionnaires.

In the second round, trimmed mean and SD for each primary, secondary and tertiary were re-calculated based on points given by ten among eleven panel participants (Fig. 3.3f). Calculating trimmed mean value in the last round is suggested as the best technique, since it eliminates biased responses of the panel members, which can alter mean values (Rowe and Wright, 2001), by ignoring the outliers (Cha and O'Connor, 2005; Hallowell and Gambatese, 2010; Markmann et al., 2013). This procedure is suggested to increase the accuracy of the data obtained through evaluation of equally weighted feedbacks received from panel members. This strategy, which is based on the calculation of trimmed mean value, is required for obtaining the final feedback from the panel members (Rowe and Wright, 2001). This particularly designed procedure ensures researchers (1) reduce vulnerability of the questionnaires, and (2) decrease the possible biases and shortcomings in the responses of panel members (Linstone and Turoff, 1975).

SD for each primary, secondary and tertiary was calculated based on the points given by ten panel members (Fig. 3.3g). SD values calculated after each round were compared with the previous round. SD was expected to decrease from round one to the next (Gunhan and Arditi, 2005b, Vidal et al., 2011). If SD does not decrease in the second round, another round should be performed (Fig. 3.3h) (Dalkey et al., 1972). According to the SD values, there was no need for conducting additional round since SD values decreased in the second round. Decrease rate of SD from first to second round is between 52%-82% that indicates building the high consensus among GB experts. Results acquired from second round of Delphi Process are presented in Appendix A.

This Delphi Procedure provides reliable and sensitive importance levels for primary, secondary and tertiary attributes. Importance levels of primary, secondary and tertiary attributes were listed and reported to the panel participants (Fig. 3.3i). This laborious Delphi inquiry was employed to achieve reliable levels of importance from highly qualified GB experts which was completed within six months.

This compelling Delphi Process provides large amounts of data sets (i.e. six different 54X7 matrix formatted data regarding seven tertiary attributes), since fifty four credits were examined for every tertiary attributes (i.e. seven project teams) under each of six secondary attributes (see Appendix A). Such a huge amount of data sets i.e. importance levels of tertiary attributes for each of fifty four credits) need to be normalized before inputted in the multi-attribute decision making method (TOPSIS) as relative weights, because relative weights should be smaller and include less redundant data. Normalization is an operation that transforms relational datasets into smaller and well-structured norm to mitigate redundancies (Shih et al., 2007). It was expected that the sum relative weights should be equal to one within individual groups and also the relative weight of the whole system should equate to one since these attributes were hierarchically structured. For this reason, Delphi Method was combined with other weight assignment methods (e.g. AHP, DR, PA) in earlier studies which intended to derive more trustworthy relative weights from a large data set (i.e. levels of importance) (Gunhan and Arditi, 2005a, b; Cha and O'Connor, 2005; Pan et al., 2012). The weight elicitation methods, which were widely combined with Delphi Method, can be listed as; (1) direct rating (DR) method, (2) point allocation (PA) method, (3) analytical hierarchy process (AHP). In addition to these, DR method is divided into two sub-types: (1) top-down direct rating (TDR) and (2) bottom-up direct rating (BDR) (Bottomley and Doyle, 2001). All these methods can be employed for weight elicitation to be used in multi-attribute (i.e. criteria) analysis; however, they do not provide the same level of reliability, flexibility, and ease of use (Pan et al., 2012).

According to the comparison analysis in previous studies (Zanakis, 1998), *TDR* which assigns maximum of 100 points to the most important attribute(s), is one of the most suggested weight elicitation method due to the following reasons: (1) Test and re-test results (i.e. *t* test, Kendall's tau-*b*, Scheffe test (post-hoc comparisons)) prove that TDR method gives more reliable results than BDR and PA (Doyle et al., 1997). Unlike TDR, in BDR method, minimum of 10 points is given to the least important attribute(s) and then the other attributes are relatively rated-up so that application of BDR is harder than TDR. (2) Similarly, studies also manifest that the application of PA are much more difficult than TDR (Doyle et al., 1997). (3) Analytic Hierarchy Process (AHP) is widely accepted; yet, AHP can examine 7±2 alternatives and 7±2 attributes (Yiu et al., 2005). However, this study requires analyzing more than 7±2 credits and 7±2 attributes; thus, AHP is not an appropriate method for this study. Among these weight assignment methods, *TDR Method* categorized under direct rating (DR) was selected to conducted with the Delphi Process for assigning first, second and third level relative weights to primary, secondary and tertiary attributes according to their importance levels obtained from Delphi Inquiry. Ease of application and higher reliability of results are the major reasons for choosing TDR method. Ease of application and higher reliability of results are the major reasons for choosing TDR method.

In this weight assignment approach, Delphi Method was used for ascertaining importance levels of every primary, secondary and tertiary attribute via expert opinion, while TDR is employed to designate relative weights of these attributes by normalizing the levels of importance to be inputted in TOPSIS as the constant numbers. According to the TDR procedure, 100 points was given to the highest trimmed mean value of attribute(s) and then the other attributes are relatively rated-down based on the levels of importance (i.e. trimmed mean) gathered in the second Delphi inquiry, and these values normalized to one same as in other weight assignment methods (Nijkamp et al., 1990). This process was separately executed for primary, secondary and tertiary attributes. Accordingly, "*qualification"* (i.e. experience, education) and "*timing of involvement"* (i.e. feasibility, SD, DD, CA) as the primary attributes in the framework were considered separately within every particular group.

Additionally, this process was executed for tertiary attributes (i.e. project teams) as follows: (1) Giving 100 points to the highest trimmed mean value of project team(s) and then relatively rating other teams based on their levels of importance which were separately executed for each credit under each of six secondary attribute (i.e. experience, education, feasibility, SD, DD, CA). (2) Then, trimmed mean values (see Appendix A) calculated from the points given by panel members in second round of Delphi Method were normalized to one within individual groups since these attributes were hierarchically designed. Moreover, the relative weight of the whole system should equate to one to utilize these relative weights in the multi-attribute decision making method (i.e. TOPSIS). The most commonly used normalization is *linear normalization* which is denoted by the following formula (Hahs-Vaughn, 2005).

$$wij=\frac{xij}{\sum_{i=1}^{m} xij}\text{, where } i=1,\ldots m;\ j=1,\ldots n;\ w_{ij}=[0,1];\ \sum w_{ij} = 1 \qquad (3.1)$$

Normalization allows deriving first level, second level and third level weights, whose sum is equal to one within that particular group. This procedure also provides that the relative weight of the whole system equate to one. Consequently, these reliable and sensitive relative weights can be used as an input in TOPSIS to determine appropriate GB certification credits that suit particular attributes of GB project delivery the most.

3.6 Results of Delphi Method-based Weight Assignment Approach

This Delphi Method based weight assignment approach provides two first level weights regarding the primary attributes (qualification and timing of involvement), six second level weights regarding the secondary attributes (i.e. experience, education, feasibility, SD, DD, CA) and forty two third level weights regarding the tertiary attributes. First, second and third level relative weights of hierarchically designed GB project delivery attributes are presented in Table 3.2.

Table 3.2: First, second and third level weights for GB project delivery attributes

No	Attributes and Sub-attributes	First Level Weights	Second Level Weights	Third Level Weights
1.	**Qualification of Project Teams in GB projects and features**	0,489051095		
1.1	**Experience of Project Teams in GB projects and features**		0,253718237	
1.1.1	Owner			0,045685368
1.1.2	General Contractor			0,040989404
1.1.3	Mechanical Team			0,034807461
1.1.4	Electrical Team			0,027039130
1.1.5	Architectural Team			0,041121861
1.1.6	Civil Team			0,032757196
1.1.7	Material Suppliers			0,031317818
1.2	**Education of Project Teams in GB projects and features**		0,235332858	
1.2.1	Owner			0,043276449
1.2.2	General Contractor			0,037507285
1.2.3	Mechanical Team			0,032699406
1.2.4	Electrical Team			0,023623762
1.2.5	Architectural Team			0,040229173
1.2.6	Civil Team			0,029569299
1.2.7	Material Suppliers			0,028427483
2.	**Timing of Project Teams' Involvement in GB Processes**	0,510948905		
2.1	**Project Teams' Involvement in Feasibility**		0,113765967	
2.1.1	Owner			0,025113395
2.1.2	General Contractor			0,017539186
2.1.3	Mechanical Team			0,016056361
2.1.4	Electrical Team			0,012777026
2.1.5	Architectural Team			0,020143749
2.1.6	Civil Team			0,010419623
2.1.7	Material Suppliers			0,011716625
2.2	**Project Teams' Involvement in Schematic Design**		0,11975365	
2.2.1	Owner			0,024709209
2.2.2	General Contractor			0,016826501
2.2.3	Mechanical Team			0,017321401
2.2.4	Electrical Team			0,013461799
2.2.5	Architectural Team			0,023119984
2.2.6	Civil Team			0,011468040
2.2.7	Material Suppliers			0,012846716
2.3	**Project Teams' Involvement in Design Development**		0,149692062	
2.3.1	Owner			0,027999081
2.3.2	General Contractor			0,022738076
2.3.3	Mechanical Team			0,021228018
2.3.4	Electrical Team			0,016919389
2.3.5	Architectural Team			0,025444921
2.3.6	Civil Team			0,016031728
2.3.7	Material Suppliers			0,019330849
2.4	**Project Teams' Involvement in Construction**		0,127737226	
2.4.1	Owner			0,021580763
2.4.2	General Contractor			0,019334485
2.4.3	Mechanical Team			0,016806624
2.4.4	Electrical Team			0,013772546
2.4.5	Architectural Team			0,020343111
2.4.6	Civil Team			0,019567867
2.4.7	Material Suppliers			0,016331830

According to the outputs from Delphi Method based weight assignment process, first level which denotes the relative weights of the "*qualification of project teams in GB projects and features"* and "*timing of project teams' involvement in GB processes"* are not drastically different from each other. Relative weight of *qualification in GB projects* is 0.489051095, while relative weight of *timing of project teams' involvement in GB processes* is 0.510948905.

Considering second level weights related to "*qualification of project teams in GB projects and features"*, relative weights of "*experience in GBs"* slightly differ from "*education/knowledge in GBs"* as weight of experience is higher than education/knowledge in GBs. Relative weight of *"experience in GBs"* is 0.253718237, while relative weight of *"education/knowledge in GBs"* is 0.235332858. Contrary to second level weights of *qualification of project teams in GB projects and features*, second level weights related to "*timing of project teams' involvement*" are different from each other. "*Involvement in design development (DD) phase"* has the highest relative weight under *timing of project teams' involvement*. Relative weight of "*involvement in DD phase"* is 0.149692062 whereas the relative weight of "*involvement in construction (CA) phase"*, which is 0.127737226. Relative weights of "*involvement in feasibility (F) phase"* and "*involvement in schematic design (SD) phase"* are different from DD and CA; while there is no big difference between relative weights of i*nvolvement in SD* and *feasibility*. *"Involvement in SD phase"* is 0.11975365, while "*Involvement in feasibility phase"* is 0.113765967.

In accordance with third level weights related to "*qualification of project teams in GB projects and features"*, the order of project teams' relative weights (third level weights) for "*experience"* and "*education"* (the secondary attributes) is same ranked in the order as follows: "*owner > architectural team > mechanical team > general contractor > civil team > material suppliers > electrical team"*. Contrary to "*qualification in GB projects and features"*, the order of project teams' relative weights (third level weights) for "*timing of project teams' involvement in GB processes"* differs from each other. The order of third level weights for "*involvement in feasibility phase"* is as follows: "*Owner>AT>GC>MT>ET>MS>CT"*. The order of third level for "*involvement in SD phase*" is as follows: "*Owner>AT>MT>GC>ET>MT>CT*". The order of third level weights under "*involvement in DD phase*" is as follows: "*Owner>AT>MT>GC>MS>ET>CT*". The order of third level weights for "*involvement in CA phase*" is as follows: "*Owner>AT>CT>AT>GC>MT>MS>ET*". In brief, third level weights show that "*owner*" and "*architectural team*" become more prominent among other identified project teams' weights in meeting with the particular requirements of GB projects and GB certification.

3.7 Discussions

The outputs of laborious Delphi Method-based weight assignment approach point out that for GB projects, particularly seek a high level GB certification, the first level weights regarding "*qualification of project teams in GB projects and features*" is slightly lower than "*timing of project teams' involvement in GB processes*". These results show that "*qualification of project teams in GBs*" and "*timing of project teams' involvements in GB processes*" work together and cannot be considered separately in the effort to optimize GB project delivery by minimizing waste throughout the GB processes. If the higher qualified project teams are involved in the GB project delivery at early stages, GB Projects would incur less waste of time, cost and labor that are highly associated with the incapacities and late involvement of the project teams. In brief, missing one of these two primary GB project delivery attributes would effectively mean that the whole mechanism is missing a critical cogwheel which in return would bring forth time-consuming and costly disruptions throughout the GB project delivery process.

These finding corroborate with previous studies (Sprau, 2009; Riley, 2009). The study conducted by Riley (2009) presents that early involvement of an experienced project team provides aid in the completion of a GB project with more cost efficient and resource efficient outcomes. In the contrary case, higher premium costs for GB projects will be resulted (Riley, 2009).

Similar to the first level weights, the second level weights of "*qualification in GB projects and features*" point out that the "*education/knowledge in GBs*" has paralleled importance as the "*experience in GBs*". This output suggests that "*experience*" and *“education*” (i.e. professional accreditation, academic degree) support each other in the process of accomplishing GB project delivery with minimal waste.

Another output related to the second level weights regarding “*timing of project teams’ involvement in GB processes”* indicate that GB project delivery are principally design driven processes therefore relative weight of *design development (DD)* phase is prominently higher than that of CA, SD and Feasibility. Although GB projects are design driven, the relative weight of DD is higher than SD because in the hierarchical framework DD phase includes as well as construction documentation (CD) while SD consists of preliminary design and project planning. In GB projects, particularly, whose owner aims at certifying their project as a high performance GB project, the importance of CD increases considerably; since GB rating systems require additional tasks to be fulfilled the GB certificate and its process. For this reason, according to the outputs from this Delphi Method based weight assignment approach, DD phase is more significant for integrating advanced green systems’ and particular credits’ requirements, and transferring Owner’s Project Objectives into the project design. If not, the negative effects of waste types being higher in construction phase is that design phase are likely to overlap with construction (Glavinich, 2008). Hence, early integration of GB features into the design phase would allow mitigation of possible time-consuming and costly disruptions that the project might incur in further stages of the GB project delivery, particularly, in construction phase through numerous change orders and reworks.

The results of the third level weights support second level weights since the relative weights of “*owner”* and “*architectural team”* who play highly critical role in GB project delivery process and GB certification process (including documentation) have the highest weights within all of the six secondary attributes (i.e. experience, education, involvement in feasibility, DD, SD, CA). Third level weights indicate that “*owner”* is extremely important for accomplishment of the GB project delivery process intending certification from a well-known GB rating system. The fact that, *owner* directs the whole GB project delivery towards their project objectives (OPR) which are the determinant of the GB project design is. Therefore, “*architectural team”* is the keystone in the GB project delivery which transfers OPR, “green” measures, GB credits and certification requirements into the design.

Lastly, the outputs regarding the first, second and third level weights prove that GB project delivery attributes (project and project team related) are all interconnected drivers for the successful achievement of GB project delivery process.

3.8 Conclusions

This research study explained in this chapter addresses the needs for designating relative weights to GB project delivery attributes that were gathered from experts through Delphi Method based weight assignment process. In this approach, Delphi Method was used for ascertaining importance levels of GB project delivery attributes via expert opinion, while TDR was employed to designate relative weights of these attributes by normalizing the importance levels. This compelling strategy is necessary for assigning sensitive and reliable relative weights to GB project delivery attributes, since these relative weights is used as inputs in the multi-attribute decision making method (i.e. TOPSIS) explained in subsequent chapter (Chapter 4). If Delphi Method based weight assignment approach was not applied before the decision making analysis (i.e. TOPSIS), the relative weights would be given by DMs (i.e. user) and this might decrease the data accuracy. As a matter fact, the reasoning mechanism of Delphi Method provides researchers increased data quality by combining several experts' judgments and thus eliminating ambiguities and inconsistency. Hence the Delphi Method based weight assignment approach allows researchers to designate reliable and sensitive relative weights to hierarchically designed attributes that can be inserted in multi-attribute decision making models in further studies.

This chapter presents a three tiered framework which was built for assigning relative weights to GB project delivery attributes, and for constituting the basis of my envisioned decision making support model. This hierarchical framework was set based on the Design-Build Method. This three tiered framework is basically divided into two major GB project delivery attributes which are: (1) *timing of project teams' involvement in GB processes* and (2) *qualification of project teams in GB project and features*. Both of these are highly critical in the pursuit of successful GB certification process with minimal waste of time and money since the underlying reasons of wasteful activities often associate to late involvement and insufficiencies of project teams in GB project delivery process. In the second level, there are six attributes (i.e. education, experience, involvement of Feasibility SD, DD, CA). Seven attributes (i.e. owner, general contractor, mechanical team, electrical team, architectural team, civil team, and material suppliers) exist under every secondary attribute. This framework developed in this study will be the basis, whose studies aim at enhancing tools for owners to provide aid in optimization of the GB project delivery to ensure successful project outcomes in terms of time, cost and sustainability.

Fifty four credits in LEED® 2009 NC under BD+C Rating System were integrated into the hierarchical framework to assign relative weights to the hierarchically designed GB project delivery attributes depending on their importance levels which have been calculated from the points given by eleven GB experts in two-rounded process of Delphi Method. This framework is developed in next chapter (Chapter 4) into an interconnected decision making support model as a guideline for determining appropriate and resource efficient (i.e. time, cost and labor) GB certification credits that suit the particular attributes of GB project delivery the most.

This study also provides the relative weights (first, second and third level weights) and the levels of importance that were attained based on the points given by eleven GB experts over two-rounded Delphi process. In each round, all of the eleven GB experts gave totally 2276 points (i.e. six 54x7 matrix, two 1x2 matrix and one 1x4 matrix) in order to designate levels of importance to the every attribute in the three tiered framework (see Appendix A). The toughest part of this Delphi Method based weight assignment process was designating relative weights to each of seven project teams (third level weight) within six secondary attributes. Accomplishing this compelling Delphi inquiry is highly valuable for the literature as every GB expert intentionally contributed in this laborious Delphi Process taking considerable time to analyze the GB project delivery process in accordance with key project teams and the requirements of a widely accepted GB rating system.

Findings of this research expressed in this chapter will provide invaluable information to the GB executives in the form of quantitative data obtained from highly qualified eleven GB experts regarding the importance of "*timing of project teams' involvement in GB processes"* and *"qualification of project teams in GB projects and features"*. Findings suggest that highly qualified GB project teams are greatly needed to convey Owner's Project Objectives (OPR), integrated green system designs and credit requirements into DD phase to effectively mitigate any possible wasteful activities in accordance with the particular attributes of the GB project delivery. The results of this study can help owners and/or owners' representatives accomplish project objectives within realistic financial and time constraints by optimizing GB project delivery and preventing unforeseen time and costs related to the limited qualifications and late involvement of the project teams. Relative weights of hierarchically designed GB project delivery attributes can be used in multi-attribute decision making models which address the issue of determining appropriate GB certification credits that suit the particular attributes of GB project delivery the most..

Following chapter (Chapter 4) presents the second part of my proposed decision making support model that engages relative weights (see Table 3.2) to be inputted into the multi-attribute decision making method (i.e. TOPSIS) for determining appropriate GB certification credits in accordance with the GB project delivery attributes. The next chapter explains how I reach my envisaged decision making support model by describing its development, application, test and validation steps.

References cited in this chapter:

Banawi, A.A. (2013) “Improving Construction Processes by Integrating Lean, Green, and Six-Sigma” PhD Dissertation. Department of Civil and Environmental Engineering. University of Pittsburgh.

Bogenstätter, U. (2000). “Prediction and optimization of life-cycle costs in earlydesign.” *Build. Res. Inf.,* 28(5/6) 376-386.

Bottomley, P. A. and Doyle, J. R. (2001). “A comparison of three weight elicitation methods: good, better, and best.” *Omega, The International Journal of Management Science,* 29(6), 53-560.

Brown, B. (1968). *A methodology used for the elicitation of opinions of experts*, The Rand Corporation, Santa Monica, Calif.

Cha, H. S. and O’Connor, J.T. (2005). “Optimizing implementation of value management processes for capital projects.” *J. Constr. Eng. Manage.* 131(2) 239-251.

Chan, A. P. C., Scott, D. and Chan, A. P. L. (2004) “Factors affecting the success of a construction project*.” J. Constr. Eng. Manage.,* 130(1), 153-155.

Chen, P.C., Kuo, K.N., Cheng, C. S., Lee, C.Y., Kuo, C.G. and Hsueh, K.L. (2013). “A modified Delphi Method to approach green energy competency criteria” *Int. J. of Technol. and Eng. Educ.*, 10(2), 9-22.

Chu, H.C. and Hwang, G. (2008). “A Delphi-based approach to developing expert systems with the cooperation of multiple experts.” *Expert Systems with Applications,* 34(4), 2826-2840.

Chua, D. K. H., Kog, Y. C. and Loh, P. K. (1999). “Critical success factors for different project ojectives.” *J. Constr. Eng. Manage.,* 125(3), 142-150.

Curtis, I. A. (2004). “Valuing ecosystem goods andservices: a new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes.” *Ecological Economics*, 50(3-4), 163-194.

Dalkey, N.C., Rourke, D.L. and Snyder, D. (1972). *Studies in the quality of life,* Lexington Books, Lexington, Mass.

Doyle, J. R., Green, R. H. and Bottomley (1997). "Judging relative importance: Dirctrating and allocation are not equivalent." *Organizational Behaviour and Human Decision Processes*, 70(1). 65-72.

Emory, W. C. and Cooper, D.R. (1991). Business research methods, Irwin, Boston.

Geist, M. R. (2010). "Using the Delphi method to engage stakeholders: A comparison of two studies." *Evaluation and Program Planning* (Special Issue) *Challenges in Evaluation of Environmental Education Programs and Policies,* 33(2), 147-154.

Glavinich, T.E. (2008). *Contractor's guide to green building construction*. John Wiley & Sons., New Jersey.

Gultekin, P., Mollaoglu-Korkmaz, S., Riley, D., and Leicht, R. (2013). "Process Indicators to Track Effectiveness of High-Performance Green Building Projects." *J. Constr. Eng. Manage.,* 139(12).

Gunhan, S. and Arditi, D. (2005a). "Factors affecting international construction." *J. Constr. Eng. Manage.*, 131(3), 273-282.

Gunhan, S. and Arditi, D. (2005b). "International expansion decision for construction companies." *J. Constr. Eng. Manage.,* 131(8), 928-397.

Hahs-Vaughn, D.L. (2005). "A primer for using and understanding weights with national datasets." *Journal of Experimental Education,* 73(3), 221-248.

Hallowell, M.R. and Gambatese, J.A. (2010). "Qualitative research: application of the Delphi method to CEM research*." J. Constr. Eng. Manage.*, 136(1): 99-107.

Hasson, F. and Keeney, S. (2011). "Enhancing rigour in the Delphi technique research." *Technological Forecasting & Social Change,* 78(9), 1695-1704.

Hilbert, M. Miles, I. and Othmer, J. (2009). "Foresight tools for participative policy-making in intergovernmental processes in developing countries: Lessons learned from the Elacc Policy Priorities Delphi." *Technological Forecasting & Social Change*, 76(7), 880-896.

Hwang, B. G. and Tan, J. S. (2010). "Green Building Project Management: Obstacles and Solutions for sustainable development, *"Sustainable Development,* 20(5), 335-349.

Hwang, B.G. and Ng, W.J. (2013)."Project management knowledge and skills for green construction: Overcoming barriers." *Int . J. of Project Manage.,* 31(2), 272-284.

Korkmaz, S., Riley, D. and Horman, M. (2010). “Piloting evaluation metrics for sustainable high-performance building project delivery.” *J. Constr. Eng. Manage.*, 136(8), 877-885.

Korkmaz S., Riley, D., and Horman, M. (2007). “Effective indictors for high performance green building delivery.” Proc., *ASCE-CIB Proc. of the 2007 Construction Research Congress,* ASCE, Reston,Va.

Krueger, T., Page T., Hubacek, K., Smith, L. and Hiscock, K. (2012) “The role of expert opinion in environmental modeling.” *Environmental Modeling & Software*, 36(2012), 4-18.

Lim, C. S., and Mohamed, M. Z. (1999). “Criteria of project success: An exploratory re-examination.” *Int. J. Project. Manage., 17*(4), 243-248.

Linstone, H. A., and Turoff, M. (Eds.). (1975). *The Delphi method: Techniques and applications.* Reading, MA: Addison-Wesley Publishing Company.

Mapp, C., Nobe, M. E. E. and Dunbar, B. (2011). “The Cost of LEED-an analysis of the construction costs of LEED and non-LEED banks”, *JOSRE,* vol. 3(1), 254-273.

Markmann, C. Darkow,I.L. and von der Gracht, H. (2013). “A Delphi-based risk analysis – Identifying and assessing future challenges for supply chain security in a multi-stakeholder environment.” *Technological Forecasting & Social Change,*, 80(9), 1815-1833.

Mitchell, V.W. (1991). “The Delphi technique: An exposition and application.” *Tech. Anal. Strat. Manage*., 3(4), 333-358.

Molenaar, K. R., Sobin, N., and Anrillón, E. (2010). “A synthesis of best-value procurement practices for sustainable design-build projects in the public sector.” *J. Green Build.,* 5(4), 148-157.

National Charette Institute (NCI) (2007). “What is a charette?” < http://www.charretteinstitute.org/charrette.html > (accessed Jan. 24, 2014).

Nijkamp, P., Rietvelt, P. and Voogd, H. (1990). *Multi-criteria evaluation in physical planning' Amsterdam: North-Holland.* Elsevier Science Publishers B.V., Amsterdam, The Netherlands.

Okoli C. and Pawlowski, S.D. (2004). “The Delphi Method as a research tool: an example, design considerations and applications.” *Information & Management*, 42(1), 15-29.

Pan, W., Dainty A. R. J. and Gibb, A. G. F. (2012). “Establishing and weighting decision criteria for building system selection in housing construction.” *J. Constr. Eng. Manage.*, 138(11), 1239-1250.

Riley, D (2009). Personal Conversation Regarding Master’s Thesis Conclusion. Pennsylvania State University, Engineering Units. 2 April 2009.

Riley, D. and Horman, M. (2005). “Delivering green buildings: High performance processes for high performance projects.” *Proc., Engineering Sustainability 2005: Conf. of the Mascaro Sustainability Initiative.*

Riley, D. R., Varadan, P. James, J. S., and Thomas, H. R. (2005). “Benefit-cost metrics for design coordination of mechanical, electrical, and plumbing systems in multistory buildings.” *J. Constr. Eng. Manage.*, 131(8), 877-889.

Robichaud, L. B. and Anantatmula, V. (2011). “Greening project management practices for sustainable construction”. *J. of Manage. in Engineering*, 27(1),48-57.

Rowe, G. and Wright, G. (2001). “Expert opinions in forecasting: The role of the Delphi technique.” *Principles of Forecasting, International Series in Operations Research & Management Science*, vol. 30, 125-144.

Rowe, G., Wright, G. and Bolger, F. (1991). “Delphi: A reevaluation of research and theory.” *Technological Forecasting and Social Change*, 39(3), 235-251.

Shih, H.-S., Shyur, H.-J. and Lee, E.S. (2007) “An extension of TOPSIS for group decision making”, *Math.and Comput. Modeling*, 45 (2007), 801-813.

Shrestha, P.P. and Pushpala, N. (2012). “Green and non-green school buildings: an empirical comparison of construction cost and sustainability.” *Proc. ASCE CRC*, 1820-1829.

Sprau, T. (2009) “Developing the Basis for Process Metrics for Sustainable Building Performance”. M.S. Thesis. Department of Architectural Engineering. The Pennsylvania State University.

Swarup, L., Korkmaz, S. and Riley, D. (2011). “Project delivery metrics for sustainable, high performance buildings.” *J. Constr. Eng. Manage.*, 137(12), 1043-1051.

Triantaphyllou, E. (2000). *Multi-Criteria Decision Making Methods: A Comparative Study*, Kluwer Academic Publishers, The Netherlands.

Turner Construction Company (2012). "*Green building market barometer."* <http://www.turnerconstruction.com/about-us/sustainability/green-market-barometer> (accessed Ap. 21, 2014).

USGBC (2009). U.S. Green Building Council. "LEED 2009 for New Construction and Major Renovations Rating System." <http://www.usgbc.org/resources/list/study-guides >, (accessed Feb.10,2014).

Vidal, L.A., Marle, F. and Bocquet, J.C. (2011). "Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects." *Expert Systems with Applications,* vol. 38, 5388-5405.

Weber, M. and Borcherding, K. (1993). "Behavioral influences on weight judgments in multi-attribute decision making." *European Journal of Operational Research*, vol.67, 1-12.

Wu, P. and Low S. P. (2010). "Project Management and Green Buildings: Lessons from the Rating Systems. "*J. of Prof. Issues in Eng. Educ. Pract*., 136(2), 64-70.

Wuellner, W.W. (1990)."Project performance evaluation checklist for consulting engineers." *J. Manage. Eng.*, 6(3), 270-281.

Yin, R. K. (2003). *Case Study Research,* Sage Publications, 3rd ed., Thousand Oaks.

Yiu, C.Y. , Ho, H.K., Lo, S.M. and Hu, B.Q. (2005) "Performance evaluation for cost estimators by reliability interval method", *J. Const. Eng. Manage.*,131(1), 108-116.

Zanakis, S. H., Solomon, A., Wishart, N. and Dublish, S. (1998). "Multi-attribute decision making: A simulation comparison of select methods." *European Journal of Operational Research Operational Research,* vol.107, 507-529.

CHAPTER 4

AN INTEGRATED DECISION MAKING APPROACH BASED ON GREEN BUILDING PROJECT DELIVERY ATTRIBUTES

4.1 Introduction

As mentioned briefly in previous chapter (Chapter 3), in order to tackle with the complexities of GB projects pursuing a GB certificate, and provide assistance for detecting appropriate GB certification credits in congruence with the existing project delivery attributes, a decision making model still remains to be a crucial necessity for the GB industry and GB literature.

The only study that hints to anything close to this is the study conducted by Kasim et al. (2012) which focuses on enhancing an intelligent dynamic reasoning tool to be employed as a regulatory assessing engine for BREEAM® (Building Research Establishment Environmental Assessment Methodology) rating system (Kasim et al., 2012). This BREEAM® based framework, conducted with BIM, aims to minimize the negative environmental impacts of buildings while increasing their environmental performance throughout their lifecycle. However, that particular study fails to address the multi-dimensional nature of the GB project delivery process as it omits to assess the existing situation of a project and project team before deciding upon which GB rating system and GB certification credits to select.

As previously discussed, analyzing the pre-existing attributes of the project and project team is critical for providing suitable recommendations for the particular conditions of the project. On the road of meeting this need, I developed a decision making support model, namely *Green Building-Credit Selection (GB-CS) Model*, which determines the most suitable GB certification credits for the particular attributes of GB project delivery process. The GB-CS Model stems from the GB project delivery attributes, i.e. timing of project teams' involvement and qualifications of project teams, that function as the backbone for a hierarchical framework in which fifty four credits of LEED® 2009 NC under BD+C Rating System are integrated (see Chapter 3).

This study explained in this chapter presents the second part of *the GB-CS Model* that addresses the detection of appropriate and resource efficient credits that correspond to the particular attributes of GB project delivery. A multi-attribute decision making method, which has the capability for detecting the best alternative(s) among a large number of alternatives, is necessary to be used for achieving this research objective according to the reasoning mechanism of multi-attribute modeling. With the aim of fulfilling this requirement, the second part of the decision making support model employs *TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution),* which warrants researchers to determine the best alternative(s) among a large number of alternatives (Triantaphyllou, 2000). In this approach, TOPSIS utilizes the relative weights attained by *the Delphi Method based weight assignment approach* as inputs.

As discussed in previous chapter (Chapter 3), Delphi Method ensures researchers increased data quality by combining several experts' judgments and eliminating ambiguities and inconsistency (Dalkey et al., 1972; Hasson and Keeney, 2011). Hence, the reasoning mechanism of *the GB-CS Model* allows to bring GB experts' knowledge together with GB project delivery attributes and to determine the GB certification credits that are more likely to be obtained in accordance with the particular attributes of GB project delivery. This integrated model as a decision making guideline aid assess the current situation of project and project teams before deciding to follow a GB rating system.

This mix-methodological study presents a flowchart illustrating how this integrated model would be utilized as guideline in selecting appropriate credits for GB certification and in assessing the existing situation of project and project team before deciding to follow a GB rating system. I tested and validated this multi-attribute decision making support model by conducting a case study on a LEED® registered residential project.

In this manner, my study fulfill the gaps in the GB literature and GB industry by developing an integrated decision making support model for determining the appropriate GB certification credits that are more likely to be obtained in an efficient and effective manner considering the particular attributes of GB project delivery. *The GB-CS Model* developed in this study is relevant to the owners whose goal is to achieve GB certification for their GB project(s). It is expected that integration of Delphi Method based weight assignment approach with TOPSIS will be useful for researchers who intend to select the best alternative(s) among large number of alternatives. It is also expected that this integrated use will a convenient approach for other multi-attribute decision making purposes.

4.2 Research Methodology

This research study explained in this chapter is conducted in four main stages: (1) reviewing literature, (2) employing TOPSIS to develop *the GB-CS Model*, (3) testing and (4) validating the *GB-CS Model*.

A literature review was performed to investigate existing multi-attribute (i.e. multi-criteria) decision making (MADM) methods and to select the method which is the most suitable for the intended purpose of my envisioned decision making support model. In this study, the fundamental criterion in selection of the MADM method is having the capability for detecting the best alternative(s) among a large number of alternatives.

The main goal of multi-attribute decision making (i.e. multi-criteria decision making) is to reflect the qualitative attributes to a framework that ensures the scientific selection of numerous alternatives. The well-known multi dimensional MCDM Methods are as follows (Triantaphyllou, 2000): (1) AHP (Analytic Hierarchy Process), (2) ELECTRE (Elimination and Choice Translating Reality), and (3) TOPSIS. All these MCDM methods support decision makers (DMs) in ranking the alternatives (i.e. credit) by using the relative weights of criteria (i.e. attributes) and numerical measures (i.e. performance scores of attributes). ELECTRE deals with outranking relations by using pairwise comparisons and it might be unable to select the best alternative because this method is better in eliminating the worst one (Benayoun et al., 1966). AHP, which is also a weight assignment method, uses pairwise comparison method, which is not suitable for this study. The reason is that AHP is able to examine 7±2 alternatives and 7±2 attributes (Shih et al., 2007), whereas in this study there are over 50 alternatives.

Based on the fundamental criterion in the selection of the MADM method, TOPSIS was chosen as the MADM method. TOPSIS, developed by Hwang and Yoon (1981) for solving a multi-attribute decision making problem, is a well known MADM method (Yue, 2011a, b). The basic concept of TOPSIS can be summarized as a ranking method that allows selecting the closest alternatives to the ideal solution (Behzadian et al., 2012). The reasons of this choice are: (1) TOPSIS is capable of ranking more than 7±2 alternatives and 7±2 attributes (Shih et al., 2007) and its reasoning mechanism is warranted to detect any credit(s) which has the shortest distance from the ideal solution (Triantaphyllou, 2000). Correspondingly, it has the capability for detecting the best alternative(s) among fifty four alternatives (i.e. credits) for predefined decision criteria (i.e. first, second and third level attributes in the three tiered framework). (2) TOPSIS is practical, easily applicable and easy to understand (Zanakis et al., 1998; Triantaphyllou, 2000). Hence, it enables to be applied by a simple computation process that can be easily programmed into a spreadsheet (Kim et al., 1997). TOPSIS was employed to reach the proposed decision making support model for determining appropriate GB certification credits because of its logical reasoning mechanism, practicality and satisfactory performance.

The whole methodology of this multi-attribute decision making support model driven by the integrated use of Delphi Method based weight assignment approach and TOPSIS is presented in Fig 4.1 by employing IDEF0 modeling language that employs an input-activity-output relation to point out its reasoning mechanism.

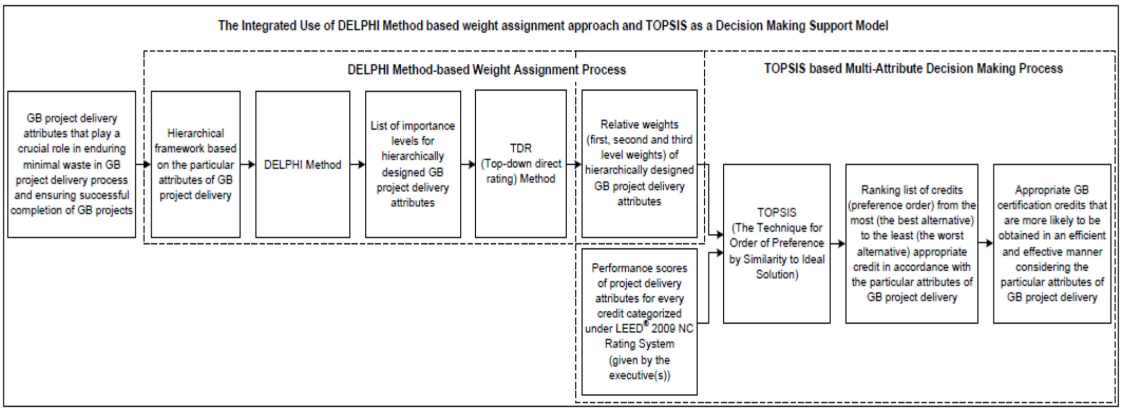

Fig 4.1: The integrated methodology for developing the GB-CS Model

In this integrated approach, it was expected that, the reasoning mechanism of TOPSIS allows examining fifty four credits as alternatives in accordance with particular attributes of GB project delivery (project and project team related) by using two types of inputs: (1) *relative weights* obtained from Delphi Method based weight assignment process (see Table 3.2 in Chapter 3), and (2) *performance scores* given by decision makers (i.e. GC and/or PM and/or authorized personnel under PM) to the GB project delivery attributes. While relative weights are inputted into TOPSIS as the constant numbers, performance scores of attributes are inputted as the variable numbers. The reason is that performance scores of GB project delivery attributes (i.e. *qualification of project teams*, *timing of project teams' involvement in GB process*es) will be changed from project to another since performance scores depend on the particulars of the existing GB project delivery attributes.

In order to test and validate this integrated decision making support model, a case study was conducted on a LEED® registered residential project in which *the GB-CS Model* was utilized for determining the appropriate credits based on the particular attributes of GB project delivery regarding this case project.

With the aim of examining the similarities and differences between the credits in the output of *the GB-CS Model* and the credits in the original checklist used in this LEED® registered residential GB project, the credits ranked from the most to the least appropriate one and detected as "YES", "MAYBE" and "NO" by *the GB-CS Model* were compared with the credits that have been already marked as "YES", "MAYBE" and "NO" in that real checklist.

4.3 TOPSIS-based Decision Making Process

The vision of developing "*an integrated decision-making guideline*" has been driving this Ph.D. research study that aims to provide help for the selection of appropriate and resource (i.e. labor, time, money) efficient GB certification credits that are more likely to be obtained in congruence with the particular attributes of GB project delivery (i.e. qualification of project teams, timing of project teams' involvement). A simple framework of this envisioned decision making support model is presented in Fig. 1.1 in Chapter 1 by using IDEF0 modeling language.

In this integrated *GB-CS Model*, TOPSIS allow to compare each alternative (i.e. credit) directly based on the data in *the decision matrixes* (i.e. performance scores given by the executive(s) to the attributes for every credit categorized under LEED® 2009 NC) and *relative weights* (i.e. first, second and third level weights attained by the Delphi Method based weight assignment approach). This utility-based method mainly addresses the need for selecting the best (optimal) alternative according to their priority rank order (preference order). The reasoning mechanism of TOPSIS enables researchers to rank alternatives based on the shortest distance from (positive) ideal solution (PIS) (i.e. the most appropriate credit) and the longest distances from the negative ideal solution (NIS) (i.e. the least appropriate credit) (Hwang and Yoon, 1981). The best alternative refers to PIS, while the worst alternative refers to the NIS (Triantaphyllou, 2000).

Tasks involved in application of TOPSIS consist of nine steps that are presented in Fig 4.2 (Triantaphyllou, 2000; Yuan et al., 2010; Yue 2011b, 2012; Behzadian et al., 2012). Each task is clarified regarding the formulas in following paragraphs, respectively (Eq. 4.1-8).

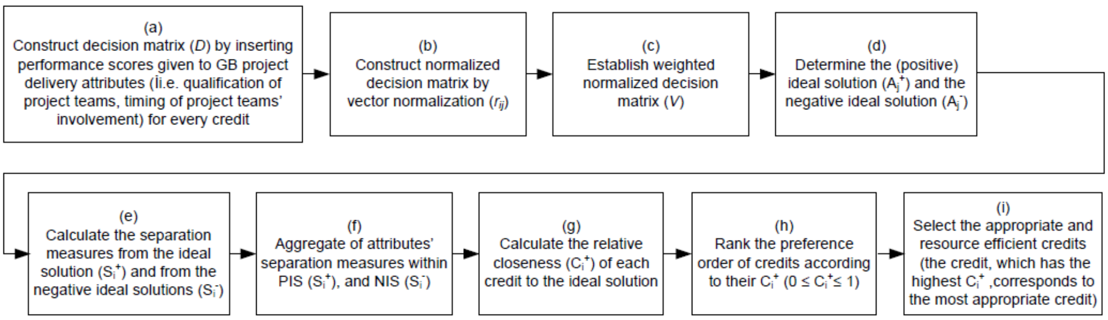

Fig 4.2: Tasks involved in the process of TOPSIS

The first step of TOPSIS is to *construct decision matrix (D)* (Eq.4.1) (Fig. 4.2a).

$$D=\begin{array}{c} \\ Y_1 \\ \vdots \\ Y_i \\ \vdots \\ Y_m \end{array}\begin{array}{c} \begin{matrix} X_1 & X_1 & \cdots & X_j & \cdots & X_n \end{matrix} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & & & & & \vdots \\ x_{i1} & & & x_{ij} & & x_{in} \\ \vdots & & & & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \end{array}, \quad i=1,\ldots m;\ j=1,\ldots n \qquad (4.1)$$

Decision matrix *(D)* refers to the m alternatives (Y_i) evaluated in terms of n attributes (i.e. decision criteria) (X_j). D is constituted by x_{ij} which denotes the performance score of the *i-th* alternative (i.e. credit) in terms of the *j-th* attribute (i.e. qualification of project teams and timing of project teams' involvement). In this study alternatives are represented by *fifty four credits* categorized under LEED® 2009 NC. Attributes, on the other hand, are indicated by *qualification (i.e. education, experience) of seven types of project teams (i.e. Owner, GC, AT, MT, ET, CT, MS)* and by *timing of these seven project teams' involvement (i.e. feasibility, SD, DD, CA)* (see Fig. 3.2).

According to TOPSIS procedures, performance scores are given by a DM (decision maker) or a group of DMs. Correspondingly, in the application of *GB-CS Model*, the performance scores are given by GC and/or PM and/or authorized personnel to the GB project delivery attributes (i.e. seven types of project teams under six different secondary attributes) for each of fifty four credits (i.e. alternatives). In this study, GC and/or PM and/or authorized personnel are defined as the secondary users of the *GB-CS Model*.

In this integrated approach, performance scores point out the average value of every project team (i.e. owner, general contractor, architectural team, mechanical team, electrical team, civil team and material suppliers); thereby, these scores alter when any of project team members change in the team or when a new team member is hired and get involved in that specific team.

In order to evaluate the particular attributes of project delivery for different aspects (i.e. involvement, education, experience) and give performance scores to these attributes, three types of scoring system were developed in this study based on nine-point scale. These scoring systems correspond to education of project teams, experience of project teams and timing of project teams' involvement, respectively. These three scoring systems are presented in Table 4.1-3.

Table 4.1: Scoring system representing *"education of project teams"*

Performance Scores	Corresponding education level of project teams (in years)
1	No education/knowledge regarding this credit.
2	0-1 years education regarding this credit
3	+1-2 years education regarding this credit
4	+2-3 years education regarding this credit
5	+3-4 years education regarding this credit
6	+4-5 years education regarding this credit
7	+5-6 years education regarding this credit
8	+6-7 years education regarding this credit
9	+7 years education regarding this credit
Note 1: This scale marks the level of specialized education regarding the particular credits.	
Note 2: In case team member is; LEED GA add 2 years, LEED AP add 4 years and LEED Fellow add 6 years more. If a professional degree (i.e. Building Engineering Modeling Professional (BEMP)) regarding this credit is considered, add 2 years more.	
Note 3: If the project concept does not include the material/equipment related to the credit, please give 1 point to the supplier.	

Table 4.2: Scoring system representing *"experience of project teams"*

Performance Scores	Corresponding experience level of project teams (in years)
1	No experience regarding this credit
2	+0-1 year experience regarding this credit
3	+1-2 years experience regarding this credit
4	+2-4 years experience regarding this credit
5	+4-6 years experience regarding this credit
6	+6-8 years experience regarding this credit
7	+8-10 years experience regarding this credit
8	+10-12 years experience regarding this credit
9	+12 years experience in GB projects
Note: If the project concept does not include the material/equipment related to the credit, please give 1 point to the supplier.	

Table 4.3: Scoring system representing *"timing of project teams' involvement"*

Performance Scores	Corresponding timing of project teams' involvement
1	This credit has not been concerned / Team has not been involved yet
2	Construction phase (Late) involvement
3	Construction phase (Early) involvement
4	Design Development phase (Late) involvement
5	Design Development phase (Early) involvement
6	Schematic Design phase (Late) involvement
7	Schematic Design phase (Early) involvement
8	Feasibility phase (Late) involvement
9	Feasibility phase (Early) involvement

The first reason of using nine-point scale in these three scoring systems is to develop detailed scoring systems for determining the levels of (1) *qualification* and (2) *timing of involvement* considering different situations that can be encountered. The second reason is to ensure that these scoring systems bring into conformity with the other nine-point scale which has been employed in the Delphi Method based weight assignment approach for designating relative weights to the particular attributes of GB project delivery (see Chapter 3).

As described in previous chapter (see Chapter 3), *"timing of project teams' involvement"* part was built considering the Design-Build method. Thus, the scoring system regarding the timing of involvement (see Table 4.3) was constituted based on Design-Build approach. In a similar manner, "*project teams"* in the framework were built based on the Integrated Project Team approach which is required for the successful delivery of GB projects (USGBC, 2014). Scoring systems regarding the project teams' education and experience (Table 4.1-2) were built considering different levels of qualifications that any project team member(s) can have.

After obtaining performance scores from executives (i.e. PM, GC or authorized personnel under PM) based on these three scoring systems regarding the education, experience and involvement of project teams, performance scores were inputted into the decision making support model to construct the decision matrixes by the authorized personnel (i.e. LEED AP). The next step is to c*onstruct normalized (i.e. standardized) decision matrix (D)* by applying vector normalization whose formula is presented in Equation 4.2 (Fig. 4.2b).

$$r_{ij}=\frac{xij}{\sqrt{\sum_{i=1}^{m} xij^2}}, \text{ where } i=1,\ldots m;\ j=1,\ldots n;\ W_{ij}=[0,1];\ \sum W_{ij} = 1 \quad (4.2)$$

In fact, three types of normalization methods can be engaged with TOPSIS to built normalized decision matrix. These methods are vector normalization, linear normalization and non-monotonic normalization (Hwang and Yoon, 1981; Yoon and Hwang, 1985; Milani et al., 2005). Among these normalization methods, vector normalization is employed in the original version of TOPSIS by performing Equation 4.2 (Triantaphyllou, 2000; Shih et al., 2007; Joshi et al., 2011; Yue et al., 2011b, 2012). In case of being all the attributes as benefit attributes, some of studies prefer to use vector normalization (Shih et al., 2007), while some of these use linear normalization (Yuan et al., 2010). However, vector normalization is the widely-used normalization method in the application of TOPSIS (Triantaphyllou, 2000; Shih et al., 2007; Joshi et al., 2011; Yue et al., 2011b, 2012). Hence, vector normalization was employed in this decision making support model by performing Equation 4.2.

The third step is to *establish the weighted normalized matrix* (*V*) (Eq. 4.3) (Fig. 4.2c).

$$V=\begin{bmatrix} w_1r_{11} & w_2r_{12} & \cdots & w_jr_{1j} & \cdots & w_n\,r_{1n} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ w_ir_{i1} & w_2\,r_{i2} & \cdots & w_j\,r_{ij} & \cdots & w_n\,r_{in} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ w_1r_{m1} & w_2r_{m2} & \cdots & w_jr_{mj} & \cdots & w_nr_{mn} \end{bmatrix} \tag{4.3}$$

A set of *relative weights*, denoted as $W = (w_1, w_2, w_3,\ldots, w_n)$, are assigned by the DM(s) and multiple with normalized matrix to acquire weighted normalized matrix (*V)*. As I described in previous chapter (Chapter 3), a critical step in the multi-criteria analysis are weight assignment procedures and related research methods employed for the derivation of reliable values to represent the relative importance of DMs' preferences. In fact, more sensitive relative weights ensure the accomplishment of more accurate results attained from MCDM analysis that is engaged for the selection of the more appropriate GB credits to be met by GB project delivery attributes. For this reason, weights should be determined with high sensitivity and reliability (Nijkamp, 1990; Weber and Borcherding, 1993). Based on this criterion, relative weights were derived through a two rounded Delphi Method based weight assignment process (see Table 3.2). These relative weights obtained by Delphi Method based weight assignment approach were inputted into the model as constant numbers.

The forth step is to *determine the (positive) ideal (PIS) and the negative ideal solutions (NIS)* (Fig. 4.2d). PIS (A^{+}) is the optimal solution in which all the attributes have the optimum performance (Eq. 4.4). Contrary, NIS (A^{-}) is the solution (i.e. decision) in which all the attributes have the worst performance (Eq. 4.5) (Yuan et al., 2010).

In this study, all the attributes are benefit attributes (i.e. experience of project teams regarding the particular credit); thereby, DMs (i.e. owner, PM, GC) wants to attain the maximum value from the alternatives. Within this approach, the maximum value can be obtained from the high performance scores given to the particular attributes of GB project delivery.

$$A_j^+ = \{(\max_i v_{ij})\ j \in J \mid i \in n\} = [v_1^+, v_2^+ \ldots, v_m^+] \quad (4.4)$$

$$A_j^- = \{(\min_i v_{ij})\ j \in J \mid i \in n\} = [v_1^-, v_2^- \ldots, v_m^-] \quad (4.5)$$

The fifth step is to *calculate the separation measures from the ideal and negative ideal solutions* which are obtained by the application of Equation 4.6-7 (Fig. 4.2e).

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2},\ i=1,\ldots,m \quad (4.6)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2},\ i=1,\ldots,m \quad (4.7)$$

S_i^+ refer to the distance from the ideal solution while S_i^- refer to the distance from the negative ideal solution.

The sixth step is to *aggregate of attributes' separation measures within PIS (S_i^+), and NIS (S_i^-),* if the framework consists of a large number of attributes (Fig. 4.2f). In this study, the framework consists of six secondary attributes (i.e. Experience, Education, Feasibility, Schematic Design (SD), Design Development (DD), Construction (CA)), so that n=6.

The seventh step is to *calculate the relative closeness (closeness coefficient) (C_i^+) to the ideal solution* which is attained by the application of Eq. 4.8 (Fig. 4.2g):

$$C_i^+ = S_i^- / S_i^+ + S_i^-,\ 0 \le C_i^+ \le 1,\ i = 1,.., m. \quad (4.8)$$

That means, if $A_i = A^+$, $C_i^+ = 1$, and if $A_i = A^-$, $C_i^+ = 0$.

The eight step of TOPSIS procedure is *to rank the preference order according to C_i^+* (Fig. 4.2h). The larger C_i^+, which has the shortest distance to the ideal solution, indicates the best the alternative(s) (i.e. credit(s) categorized under LEED® 2009 NC Rating System) (Triantaphyllou, 2000; Shih et al., 2007).

In this study, the credit, which has the highest C_i^+, corresponds to the most appropriate credit among the list of credits in LEED 2009® NC based on the GB project delivery attributes aforementioned (i.e. qualification of project teams and timing of project teams' involvement). In fact, TOPSIS warrants that any alternative, which has the shortest distance from the ideal solution, has the longest distance from the negative-ideal solution (Triantaphyllou, 2000). Thus, *GB-CS Model* ensures detection of appropriate credits that suit the particular attributes of GB project delivery the most.

The relative closeness values and *the preference order* of credits within the GB rating system will be considered by the owner and/or owner's representative, (i.e. the end-user), to select appropriate credits that are more likely to be obtained in an efficient and effective manner considering the particular attributes of GB project delivery to get sufficient points for GB certification and to accomplish project objectives on time and within budget. In this manner, *the relative closeness* and *the preference order* (ranking list of credits from the highest to the lowest C_i^+), which are presented in the output attained from *the GB-CS* Model, provides considerable aid to the owners in the selection of appropriate and resource efficient credits to be fulfilled by the project and project team (Fig. 4.2i). In this study, the preference order is named as "ranking list" to be easily perceived by the owners and/or owners' representatives.

In Fig 4.3, the flowchart of this decision making support model is presented to describe how *the GB-CS Model* would be utilized as guideline in selecting appropriate credits for GB certification and in assessing the existing situation of project and project team before deciding to follow a GB rating system to achieve GB certification while enduring minimal waste of time, cost and labor in GB project delivery process.

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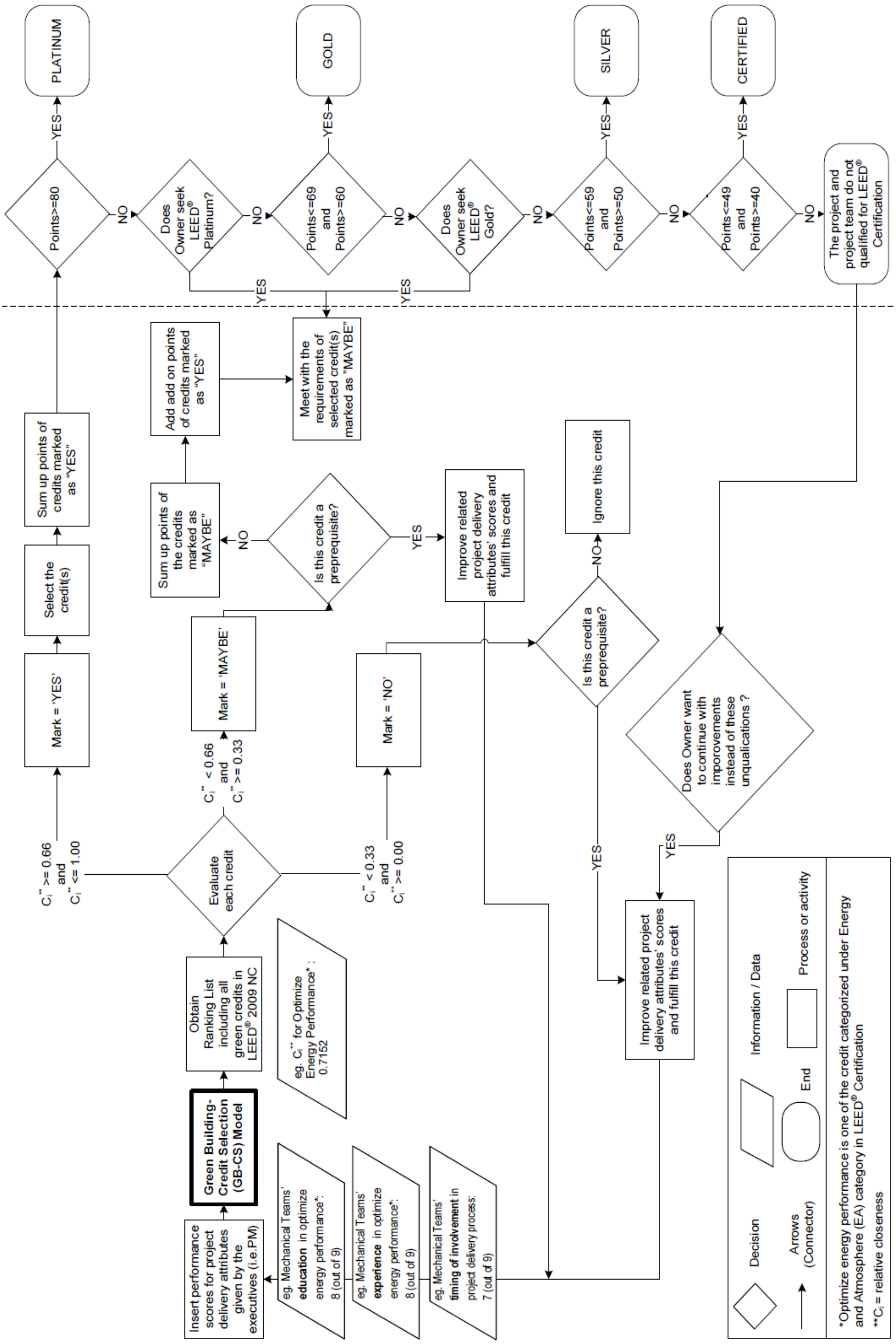

Fig 4.3: The flowchart for the usage of *GB-CS Model*

In order to make the preference order (ranking list) more understandable for owners and to provide guidance them in the selection of the suitable credits, *relative closeness* values (C_i^+) were brought into conformity with LEED® certification checklist. For this, the range of [0, 1], where C_i^+ is defined, was divided into three sub-groups: [0.00, 0.33), [0.33, 0.66), [0.66, 1.00]. These three sub-groups refer to "NO", "MAYBE" and "YES", respectively, since the credits are marked as "NO", "MAYBE" and "YES" in the LEED® checklist. LEED® checklist is used as a roadmap during the GB project delivery process from the date of registering for LEED® Certification Program. The evaluation scale developed in this study for detecting credits as "YES", "MAYBE" and "NO" is presented in Table 4.4.

Table 4.4: Evaluation scale for relative closeness values

The range of C_i^+	**Corresponding mark in LEED® checklist**
$0.66 \leq C_i^+ \leq 1.00$	YES
$0.33 \leq C_i^+ < 0.66$	MAYBE
$0.00 \leq C_i^+ < 0.33$	NO

According to this evaluation scale, if *the relative closeness* of any credit is within the range of [0.66, 1.00], this credit is marked as "YES" in the checklist. Credit(s) determined as "YES" imply that the particular attributes of project delivery (project and project team related) are more likely to meet with the specific requirements of this/these credit/s. On the contrary, if *the relative closeness* of any credit is within the range of [0.00, 0.33), this credit is marked as "NO" in the checklist. Credit(s) detected as "NO" denote that these credits cannot be fulfilled by the particular attributes of existing project and project team. If C_i^+ of any prerequisite is within the range of [0.00, 0.33), project delivery process and project teams are needed to be improved to fulfill both the specific requirements of LEED® certification and prerequisites, because prerequisites are the major credits and must be satisfied to accomplish LEED® Certification. Add to these, if C_i^+ of any credit is within the range of [0.33, 0.66), this credit(s) is marked as "MAYBE" in the checklist. Credit(s) determined as "MAYBE" means that some improvements are required to fulfill these credits such as employment of new team member(s) qualified in regarding the credit(s). If these personnel get involved in early phases of the GB project delivery process, their qualification would drastically increase the design efficiency and would ensure project teams attain the GB certificate with minimal wasteful activities.

In accordance with the ranking list and evaluation scale, the owner should initially consider credits marked as “YES” and sum them up. If this summation of credits does not fulfill the required threshold to get the GB certificate the owner seeks to earn, the owner should repeat the same process for the credits marked as “MAYBE” according to the order in ranking list (Fig. 4.3). In the LEED 2009®, thresholds for LEED® Platinum, Gold, Silver and Certified are 40, 50, 60 and 80 respectively. If the owner chooses the credit(s) marked as “MAYBE”, the owner should take improvement into consideration. In the process of applying these procedures, general rules of LEED® Certification Program always must be regarded.

In order to ensure the users (i.e. the owner, GC, PM) of *GB-CS Model* additional insight into how much financial load each of the LEED credits would introduce to the project, *"Added Cost Ratio"* of each credit was integrated into the model. In this study, *"Added Cost Ratio"*, which refers to the additional cost ratio regarding the credit, equates to the ratio of *"Added Cost of a Credit"* to the *"Total Cost of the Project"*. However, the evaluation of additional cost for each credit in a GB rating system is not within the scope of this research. Hence, add cost information integrated into the model, was gathered from prior studies addressing this issue (Stegall, 2004; GSA, 2004). Nevertheless, evaluating additional cost for each credit in a GB rating system is hard, and requires detailed work, highly qualified project teams and a long time. Thus, add cost information regarding each credit in a LEED Rating System is limited in the literature. In fact, the reference studies only analyzed added first cost for some credits in earlier versions of LEED® NC Rating System.

One of the reference study examined additional cost of the credits by calculating extra cost spent for the fulfillment of those credits during design and construction phases (Stegall, 2004). The study conducted by Stegall (2004) focused on hard and soft first costs spent for earning LEED® Silver Certification. In this study, add cost information of credits refers the sum of additional material cost and labor cost (personnel fees related to time and cost), while add cost of compiling the LEED® submittal documentation refer the additional labor cost. This study indicates that integration of the design features to achieve LEED® Silver Certification lead to increase higher project cost. According to this study, compiling the LEED® submittal documentation is the major source of additional labor cost (Stegall, 2004). This finding indicates that time spent for compiling LEED® submittal documentation is higher than that of the other activities performed to fulfill the credits examined in that study. Hence, this study presents that personnel having insufficient experience in LEED documentation can incur higher labor costs than required to compile the documentation. The results of this study conducted by Stegall (2004) corroborate with the findings of Delphi Method which I performed to rank the waste types and related root causes in GB project delivery process (see Chapter 2).

The other study examined additional soft cost of credits that includes cost of LEED® design team and LEED® documentation (GSA, 2004). The conducted by GSA (2004) focused on calculating additional soft cost for LEED® Silver and Gold Certification. This study analyzed: cost of green design systems, cost of Multiple Credits tasks, compiling LEED® documentation, modeling to satisfy LEED®, commissioning for LEED®. Multiple Credits tasks consist of: (1) feasibility reviews charette, (2) material and systems research for LEED® credits, (3) coordination of LEED® "Action Items" with Design Team, (4) LEED® calculations for site, water and material IEQ credits, (5) LEED® credit interpretation reviews and/or submissions, (6) development for LEED, (7) meeting(s) or review for LEED®, (8) review contractor submittals, (9) general LEED® integration efforts (Architect), (10) reimbursable expenses for all design team tasks (GSA, 2004).

In this manner, the output from the integrated *GB-CS Model* includes (see Table 4.6): (1) *relative closeness* (C_i^+) of every credit, (2) *preference order* (ranking list) of credits according to their relative closeness, (3) *add first cost ratio information* for each credit and (4) *green points* correspond to every credit which obtained from the LEED® 2009 NC checklist. This informative output ensures the owners and/or owners' representatives easily comprehend the limitations of project and project teams for each credit. This output enable them realize which credits are more likely to be met by the existing attributes of GB project delivery. This output also provides them understand which level of certification can be earned by these current attributes, and which credit/s is/are needed some improvements to be fulfilled to obtain the targeted level of GB certificate or higher level of GB certificate. It is expected that integrating additional cost ratio regarding each credit will allow the owner estimate the approximate costs associated with project improvements to attain the credits within the predetermined limits of the budget while decreasing possible unforeseen expenditures connected with the pursued LEED credits.

4.4 Testing the Decision Making Support Model

In order to test and verify the *GB-CS Model*, I conducted a case study on a LEED® registered residential GB project in which this decision making support model was utilized for determining the appropriate credits based on the GB project delivery attributes. With the aim of validating this integrated model, the credits marked as “YES”,”MAYBE” and ”NO” according to their *relative closeness* and *evaluation scale* were compared with the credits in the real checklist employed in this residential project. The main features of this project (P1) are presented in Table 2.1. This project is one of three GB projects examined in this research (see Chapter 2).

Background of the Test and the GB Project

This LEED® registered residential GB project, on which *the GB-CS Model* was tested by performing a case study, is based on "Revenue Sharing Model” which is a Design-Build-Sell concept. "Revenue Sharing Model” depends on the revenue instead of housing units (TOKI, 2014). In order to generalize the specifics of my particular case study, the following differentiation has been made for the contractor team: Contractor's Executive Board carries the entire owner's authority and decision making rights/responsibilities hence denoted as the owner (Contractor's Executive Board). Whereas, the contractor's project management team in charge of all organizations at site is considered as the contractor (project management team). Mechanical, electrical, architectural and civil teams are responsible for both design and build. Preliminary design and material take-off (MTO) studies are assumed to be done in-house by the "owner" early in the feasibility phase.

In this project, the general contractor (PM team) is involved in feasibility phase, while the architectural, mechanical and electrical teams are involved in the process at the beginning of schematic design phase. The owner (Contractor's Executive Board) built up the civil team and make contracts with suppliers at the end of design development and/or in construction phase.

Although the owner has more than 10 years professional experiences in construction industry, they have little and/or no experience and/or education in GB rating systems. Contrary, one LEED® AP (Accredited Professional) BD+C, who is Civil and Environmental Engineer with M.Sc. degree, works in PM team. This employee is the Sustainable Projects Coordinator and has more than five years professional experiences in GB projects and earlier versions of LEED® Rating System. Architectural team includes professionals who are LEED AP and have almost 5 years experiences in some credits of previous versions of LEED® NC Rating Systems. Most of professionals in civil team are experienced architects and civil engineers. However some of these personnel in civil team have no experience in GB projects, some of them have experiences in some credits in LEED® NC Rating System. Although, mechanical and electrical team members have almost 8-10 years professional experiences and civil team members have almost 5 years professional experiences in construction industry, they have little and/or no experience and/or education in prior versions of LEED® Rating Systems. Suppliers, on the other hand, have experiences in some credits that address their professions. All the employees have at least Bachelor degree related to construction industry. Most of the personnel in each team have M.Sc. degree related to construction while an employee in the electrical team has Ph.D. degree.

In order to build the decision matrixes (*D*), performance scores were given by the Sustainable Projects Coordinator to each seven project team (i.e. third level attribute) for each fifty four credits considering the levels of their education and experience regarding each credit, and the timing of their involvement in the processes of that residential GB project. Performance scores regarding education and experience of project teams, and performance scores regarding the timing of project teams' involvement were given according to three scoring systems developed in this study (see Table 4.1-3). Performance scores of each attribute given for each credit refer the average score of regarding the team.

These performance scores were inserted into the *GB-CS Model* to construct decision matrixes (*D*). Relative weights obtained by Delphi Method based weight assignment approach have been already inputted into the model as the constant numbers.

4.5 Test Results of the Decision Making Support Model

When the performance scores given by the Sustainable Projects Coordinator were inputted, two types of data were obtained via TOPSIS. These two types of data are (1) *relative closeness* (C_i^+) of every credit in LEED® 2009 NC (i.e. 54 credits) and (2) *preference order* (ranking list) according to the credits' relative closeness (C_i^+). In the preference order, the credits are ranked from the most to the least appropriate one according to their C_i^+ obtained by TOPSIS. Within this study, the credit with the highest relative closeness (i.e. the closest alternative to the ideal solution) corresponds to the most appropriate credit, while the credit with the lowest relative closeness (i.e. the farthest alternative to the ideal solution) corresponds to the least appropriate credit. The output obtained via TOPSIS is presented in Table 4.5. In this table, *separation measure* of each credit (i.e. from the positive ideal solution and from the negative ideal solution), that were calculated based on the existing GB project delivery attributes of this LEED® registered residential project, are also given. The output, which is to be considered by the owners and/or owners' representatives, is displayed in Table 4.6. These outputs (i.e. separation measures, relative closeness and preference order) presented in Table 4.5 and Table. 4.6 refer to the test results that were obtained by conducting the case study on the LEED® registered residential GB project.

Table 4.5: Test Results of TOPSIS within GB-CS Model by Conducting a Case Study on a LEED® Registered Residential GB Project

A Case Study Conducted with the Aim of Applying Green Building Credit Selection Model to Determine Appropriate Credits for GB certification based on Green Building Project Delivery Attributes				
$C_i^* = S_i' / (S_i' + S_i^*)$ $0 < C_i^* < 1$, $i = 1,2,\ldots,m$ $C_i^* = 1$ if and only if the alternative is the best alternative $C_i^* = 0$ if and only if the alternative is the worst alternative	Separation Measures (PIS (S_i^+), and NIS (S_i^-))		Relative Closeness (C_i^*)	Preference Order according to C_i^*
Credits categorized under LEED® 2009 for New Construction and Major Renovations Rating System	S_i^* (distance from the positive ideal solution)	S_i' (distance from the negative ideal solution)	C_i^* $0<C_i^*<1$	Rank
Sustainable Sites				
Construction Activity Pollution Prevention	0,0261995831	0,0171964247	0,3962674353	19
Site Selection	0,0207180232	0,0269066070	0,5649725132	3
Development Density and Community Connectivity	0,0192614601	0,0273500662	0,5867661581	2
Brownfield Redevelopment	0,0351632949	0,0033805922	0,0877076083	54
Alternative Transportation—Public Transportation Access	0,0207180232	0,0269066070	0,5649725132	4
Alternative Transportation—Bicycle Storage and Changing Rooms	0,0183344017	0,0225602859	0,5516678878	5
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	0,0283717450	0,0173767582	0,3798322781	27
Alternative Transportation—Parking Capacity	0,0340881942	0,0083225006	0,1962358942	47
Site Development—Protect or Restore Habitat	0,0141006474	0,0278139398	0,6635861559	1
Site Development—Maximize Open Space	0,0333575587	0,0082846549	0,1989484754	46
Stormwater Design—Quantity Control	0,0333878999	0,0080783832	0,1948181176	49
Stormwater Design—Quality Control	0,0333878999	0,0080783832	0,1948181176	50
Heat Island Effect—Non-roof	0,0277935582	0,0166753447	0,3749888937	28
Heat Island Effect—Roof	0,0278453343	0,0162967426	0,3691883966	31
Light Pollution Reduction	0,0340881942	0,0083225006	0,1962358942	48
Water Efficiency				
Water Use Reduction—20% Reduction	0,0271935983	0,0170218342	0,3849749569	25
Water Efficient Landscaping	0,0275330339	0,0178837408	0,3937695032	22
Innovative Wastewater Technologies	0,0282353960	0,0158231204	0,3591387484	34
Water Use Reduction	0,0271935983	0,0170218342	0,3849749569	26
Energy and Atmosphere				
Fundamental Commissioning of Building Energy Systems	0,0249650792	0,0183551541	0,4237085698	9
Minimum Energy Performance	0,0273570619	0,0174275758	0,3891418285	24
Fundamental Refrigerant Management	0,0286679898	0,0186751699	0,3944639525	20
Optimize Energy Performance	0,0277530120	0,0164426085	0,3720415803	30
On-Site Renewable Energy	0,0336804442	0,0088106899	0,2073536076	44
Enhanced Commissioning	0,0302314626	0,0121283420	0,2863172316	39
Enhanced Refrigerant Management	0,0286679898	0,0186751699	0,3944639525	21
Measurement and Verification	0,0330686603	0,0088304180	0,2107544680	42
Green Power	0,0336804442	0,0088106899	0,2073536076	45
Materials and Resources				
Storage and Collection of Recyclables	0,0265826595	0,0180024413	0,4037770694	17
Building Reuse—Maintain Existing Walls, Floors, and Roof	0,0345010980	0,0077420318	0,1832731572	52
Building Reuse—Maintain 50% of Interior Non-Structural Elements	0,0345010980	0,0077420318	0,1832731572	53
Construction Waste Management	0,0273460353	0,0155610084	0,3626679220	33
Materials Reuse	0,0296545543	0,0156109142	0,3448746861	35
Recycled Content	0,0296545543	0,0156109142	0,3448746861	36
Regional Materials	0,0294132436	0,0169790615	0,3659887453	32
Rapidly Renewable Materials	0,0273121733	0,0181907780	0,3997713877	18
Certified Wood	0,0333024662	0,0088930596	0,2107583550	41
Indoor Environmental Quality				
Minimum Indoor Air Quality Performance	0,0274642504	0,0186731312	0,4047288892	16
Environmental Tobacco Smoke (ETS) Control	0,0238370644	0,0217022896	0,4765612096	7
Outdoor Air Delivery Monitoring	0,0339138176	0,0079558903	0,1900154244	51
Increased Ventilation	0,0268397806	0,0189704800	0,4141098468	12
Construction IAQ Management Plan—During Construction	0,0275167381	0,0187709294	0,4055276586	15
Construction IAQ Management Plan—Before Occupancy	0,0311598520	0,0161063209	0,3407578812	37
Low-Emitting Materials—Adhesives and Sealants	0,0252383756	0,0174768680	0,4091482704	13
Low-Emitting Materials—Paints and Coatings	0,0252383756	0,0174768680	0,4091482704	14
Low-Emitting Materials—Flooring Systems	0,0265271042	0,0170908919	0,3918312030	23
Low-Emitting Materials—Composite Wood and Agrifiber Products	0,0327599537	0,0085711553	0,2073778198	43
Indoor Chemical and Pollutant Source Control	0,0321395065	0,0096176991	0,2303242993	40
Controllability of Systems—Lighting	0,0232711784	0,0196592393	0,4579326354	8
Controllability of Systems—Thermal Comfort	0,0204538578	0,0212631894	0,5097002502	6
Thermal Comfort—Design	0,0279019533	0,0165971954	0,3729778181	29
Thermal Comfort—Verification	0,0297175952	0,0153311283	0,3403232566	38
Daylight and Views—Daylight	0,0261218587	0,0188471308	0,4191139501	10
Daylight and Views—Views	0,0261218587	0,0188471308	0,4191139501	11

Table 4.6: The output of the Green Building-Credit Selection Model

LEED® Ceritification Levels	Evaluation Scale	Rank	Ci* (relative closeness)	Ranking List of LEED® 2009 NC Credits based on GB Project Delivery Attributes	Environmental Points	Add Cost Ratio for LEED Silver Certificate (Stegall, 2004) (LEED design and construction cost)	Add Cost Ratio for LEED Silver Certificate (GSA, 2004) (LEED design cost)	Additional Cost Ratio for LEED Gold Ceritficate (GSA, 2004) (LEED design cost)
CERTIFIED* SILVER** GOLD*** PLATINUM****	YES	1	0,6636	Site Development—Protect or Restore Habitat	1	N/A	N/A	N/A
		2	0,5868	Development Density and Community Connectivity	5	N/A	N/A	N/A
		3	0,5650	Site Selection	1	N/A	N/A	N/A
		4	0,5650	Alternative Transportation—Public Transportation Access	6	N/A	N/A	N/A
		5	0,5517	Alternative Transportation—Bicycle Storage and Changing Rooms	1	N/A	N/A	0,017%
		6	0,5097	Controllability of Systems—Thermal Comfort	1	N/A	N/A	N/A
		7	0,4766	Environmental Tobacco Smoke (ETS) Control	Prerequisite	N/A	N/A	N/A
		8	0,4579	Controllability of Systems—Lighting	1	N/A	N/A	N/A
		9	0,4237	Fundamental Commissioning of Building Energy Systems	Prerequisite	0,398%	N/A	N/A
		10	0,4191	Daylight and Views—Daylight	1	N/A	N/A	N/A
		11	0,4191	Daylight and Views—Views	1	N/A	N/A	N/A
		12	0,4141	Increased Ventilation	1	N/A	N/A	N/A
		13	0,4091	Low-Emitting Materials—Adhesives and Sealants	1	0,003%	N/A	N/A
		14	0,4091	Low-Emitting Materials—Paints and Coatings	1	0,033%	N/A	N/A
		15	0,4055	Construction IAQ Management Plan—During Construction	1	0,171%	N/A	N/A
		16	0,4047	Minimum Indoor Air Quality Performance	Prerequisite	0,797%	N/A	N/A
		17	0,4038	Storage and Collection of Recyclables	Prerequisite	N/A	N/A	N/A
		18	0,3998	Rapidly Renewable Materials	1	N/A	N/A	N/A
	MAYBE	19	0,3963	Construction Activity Pollution Prevention	Prerequisite	N/A	N/A	N/A
		20	0,3945	Fundamental Refrigerant Management	Prerequisite	N/A	N/A	N/A
		21	0,3945	Enhanced Refrigerant Management	2	N/A	N/A	N/A
		22	0,3938	Water Efficient Landscaping	2 to 4	N/A	N/A	N/A
		23	0,3918	Low-Emitting Materials—Flooring Systems	1	N/A	N/A	N/A
		24	0,3891	Minimum Energy Performance	Prerequisite	N/A	N/A	N/A
		25	0,3850	Water Use Reduction—20% Reduction	Prerequisite	N/A	N/A	N/A
		26	0,3850	Water Use Reduction	2 to 4	N/A	N/A	N/A
		27	0,3798	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3	N/A	N/A	N/A
		28	0,3750	Heat Island Effect—Non-roof	1	0,033%	N/A	N/A
		29	0,3730	Thermal Comfort—Design	1	0,076%	N/A	N/A
		30	0,3720	Optimize Energy Performance	1 to 19	0,183%	0,040%	0,040%
		31	0,3692	Heat Island Effect—Roof	1	0,108%	N/A	0,010%
		32	0,3660	Regional Materials	1 to 2	N/A	N/A	N/A
		33	0,3627	Construction Waste Management	1 to 2	N/A	N/A	N/A
		34	0,3591	Innovative Wastewater Technologies	2	N/A	N/A	N/A
		35	0,3449	Materials Reuse	1 to 2	N/A	N/A	N/A
		36	0,3449	Recycled Content	1 to 2	N/A	N/A	N/A
		37	0,3408	Construction IAQ Management Plan—Before Occupancy	1	N/A	N/A	N/A
		38	0,3403	Thermal Comfort—Verification	1	N/A	N/A	N/A
		39	0,2863	Enhanced Commissioning	2	0,120%	N/A	N/A
		40	0,2303	Indoor Chemical and Pollutant Source Control	1	N/A	N/A	N/A
		41	0,2108	Certified Wood	1	0,158%	N/A	N/A
		42	0,2108	Measurement and Verification	3	0,135%	0,018%	0,018%
		43	0,2074	Low-Emitting Materials—Composite Wood and Agrifiber Products	1	0,038%	N/A	N/A
		44	0,2074	On-Site Renewable Energy	1 to 7	N/A	N/A	0,053%
		45	0,2074	Green Power	2	N/A	N/A	N/A
	NO	46	0,1989	Site Development—Maximize Open Space	1	N/A	N/A	N/A
		47	0,1962	Alternative Transportation—Parking Capacity	2	N/A	N/A	N/A
		48	0,1962	Light Pollution Reduction	1	N/A	N/A	N/A
		49	0,1948	Stormwater Design—Quantity Control	1	N/A	N/A	N/A
		50	0,1948	Stormwater Design—Quality Control	1	N/A	N/A	0,005%
		51	0,1900	Outdoor Air Delivery Monitoring	1	0,012%	0,007%	0,007%
		52	0,1833	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3	N/A	N/A	N/A
		53	0,1833	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1	N/A	N/A	N/A
		54	0,0877	Brownfield Redevelopment	1	N/A	N/A	N/A
			not included	Innovation in Design (Bonus Credits)	6			
			not included	Regional Priority (Bonus Credtis)	4			
				SUBTOTAL	**110**	**2,265%**	**0,065%**	**0,149%**
				Cost of Multiple Credits Tasks (related to personnel fees)		N/A	0,146%	0,169%
				Cost of Compilling LEED Documentation* (related to personnel fees)		0,486%	0,024%	0,028%
				Modelling to satisfy LEED (related to personnel fees)		0,064%	N/A	N/A
				Commissioning for LEED (related to personnel fees)		0,518%	N/A	N/A
				Cost of LEED Registration and Certification Fees		0,014%	0,017%	0,017%
				SUBTOTAL (Soft costs ratio directly associated with LEED personnel)		**1,068%**	**0,170%**	**0,197%**
				TOTAL	**110**	**2,766%**	**0,252%**	**0,363%**

Note 1:	*Multiple Credits tasks includes (1) feasiblity reviews charette, (2) material and systems research for LEED credits, (3) cordination of LEED "Action Items" with Design Team, (4) LEED calculations for site,water and material IEQ credits, (5) LEED credit interpretation reviews and/or submissions, (6) develoment for LEED, (7) meeting(s) ro review LEED, (8) review contractor submittals, (9) general LEED integration efforts (Architect), (10) reimbursal expenses for all design team tasks (% 0.010)
Note 2:	Add soft cost outputs of GSA (2004) used in this table was calculated based on a design team with Expert Consultant. This study calculated the same credits performed by experienced Design Team. The difference between these two calculation occur in "multiple credits tasks" and "compilling documentation" which are associated with man/hour spent for these tasks. Soft costs of compilling LEED documentation done by experienced team is %0.028 for LEED Silver and %0,035 for LEED Gold.Soft cost of multiple credits tasks done by experienced team is %0,153 for LEED Silver and LEED Gold.
Evalution Scale:	$0.66 \leq Ci^* \leq 1.00$: YES $0.33 \leq Ci^* < 0.66$: MAYBE $0.00 \leq Ci^* < 0.33$: NO
Tresholds:	Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110 points

According to *the relative closeness* values attained via TOPSIS (Table 4.5-6), sixteen credits are within the range of [0.00, 0.33); and thus these credits were determined as "NO" in regard to *the evaluation scale* presented in Table 4.4. On the contrary, only one credit is within the range of [0.66, 1.00]; thereby, it was detected as "YES". Thirty seven credits including the prerequisites are within the range of [0.33, 0.66); accordingly identified as "MAYBE".

"Site Development-Protect and Restore Habitat" whose relative closeness is 0.6636 out of 1.00, was detected as *the most suitable and resource efficient credit* by *the GB-CS Model*. Contrary, "Brownfield Development" whose relative closeness is 0.0877 out of 1.00, was detected *the least appropriate credit* by the GB-CS Model.

The relative closeness (C_i^+) values of prerequisites are within the range of [0.33, 0.66) for this project (Table 4.5-6). Prerequisites are obligatory credits and must be satisfied to earn the certificate in regard to the procedures of LEED® Certification Program. Prerequisites in LEED® 2009 NC are Construction Activity Pollution Prevention, Water Use Reduction-20% Reduction, Storage and Collection of Recyclables, Minimum Energy Performance, Fundamental Commissioning of Building Energy Systems and Fundamental Refrigerant Management, Minimum Indoor Air Quality Performance and Environmental Tobacco Smoke (ETS) Control, whose relative closeness (C_i^+) are 0.3963, 0.3850, 0.4038, 0,3891, 0.4237, 0,3945, 0.4047, 0.4766, respectively, for the residential project described above (Table 4.5-6). According to *the relative closeness* of prerequisites and *the evaluation scale,* these mandatory credits were detected as "MAYBE" for this project by *the GB-CS Model,* since *the relative closeness* of prerequisites are within the range of [0.33, 0.66). These results suggest that this project and its project teams should be improved to efficiently satisfy the specific requirements of prerequisites to achieve GB certificate.

Although the most important credit in promoting energy efficiency in buildings is "Optimize Energy Performance", its *relative closeness* is 0.3720 for this residential project stated above. In fact, fulfillment of this credit provides 1-19 points that are the highest points among all the credits in LEED® 2009 NC Rating System. However, according to its *relative closeness* (C_i^+), it was detected as "MAYBE" by the *GB-CS Model* for this LEED® registered residential project. If the owner prefers to deal with low C_i^+ of "Optimize Energy Performance", the performance scores would be revised after improving the relevant team. The owner could choose to employ expert(s) in Energy Modeling who are LEED AP and Building Engineering Modeling Professionals (BEMP) and who have sufficient experience (i.e. 10 years of experience) in previous versions of LEED® rating systems. If this specialist is involved in early Schematic Design, his/her qualifications would drastically increase the design efficiency and prevent accumulation of excessive time and costs in subsequent phases of the project as the project would be designed properly at the initial stage in the light of their valuable inputs about regarding credits. Furthermore, the owner could hire highly educated professionals who have at least 5 years of experience in GBs in earlier versions of LEED® rating system(s) and in the regarding credits. They would use the data obtained from the Energy Modeling Specialist in project design and construction.

If the project and project teams would be improved based on the abovementioned suggestions, these revised performance scores would be given once again using Table 4.1-3 to re-construct decision matrixes. In order to attain *the renewed relative closeness* (C_i^+) for the credits in LEED® 2009 NC, *the revised performance scores* would be once again inserted into the *GB-CS Model.*

When these revised performance scores are inputted into *the GB-CS Model,* $\mathrm{C_i^+}$ of "Optimize Energy Performance" drastically increase from 0.3720 to 0.7152 (see Appendix B). The ranking list of credits is renewed according the improved $\mathrm{C_i^+}$values attained by TOPSIS. This *revised ranking list of credits* presents that "Optimize Energy Performance" is detected as *the most suitable and resource efficient credit* by *the GB-CS Model* for this improved case. This considerable increase in the relative closeness of "Optimize Energy Performance" indicates that this improved process and renewed project teams can be sufficient to meet with particular requirements of this credit.

Depending on these outputs, the owner of this LEED® registered residential project is suggested to target at earning LEED® Certified rather than LEED® Platinum, Gold, Silver and corresponding credits whose C_i^+ are within the range of [0.3720, 0.6636]. The reason is that C_i^+ of fifty three credits are lower than 0.66 according to the current attributes of this GB project delivery. If the owner wants to seek higher level of GB certification, they can easily find which additional credits are more suitable to undertake by simply going down the credit ranking list developed for the whole GB rating system (see Table 4.6). In order to earn higher level certificate, they have to earn higher points. For this purpose, they might have to deal with the credits that receive lower C_i^+ by building more efficient project teams and/ or getting them involved in the process in a timely fashion.

With the overall intention to validate *the GB-CS Model*, I compared *the credits ranked from the most to the least appropriate one* according to their $\mathrm{C_i^+}$ (see Table 4.6) with *the credits in the real checklist* used in this residential GB project. In order comprehensively examine the similarities and differences between credits obtained from *the GB-CS Model* and credits in the original checklist applied in this GB project, I compared the credits detected as "YES","MAYBE" and "NO" according to $\mathrm{C_i^+}$ by *the GB-CS Model* with the credits that have been already determined as "YES","MAYBE" and "NO" in the real checklist. I determined four criteria for comparing the credits. In order to validate *the GB-CS Model,* at least two of these four criteria should be fulfilled.

The first criterion for validating the *GB-CS Model* is that the most appropriate and resource efficient credit (i.e. the closest alternative to the ideal solution) determined by the *GB-CS Model* should have been already determined as "YES" in the original checklist used in this GB project. The reason is that the reasoning mechanism of TOPSIS guarantees to detect the best alternative which is the closest alternative to the ideal solution. The best alternative is any alternative which has the highest C_i^+. In regard to the test and comparison results, the credit (i.e. Site Development-Protect and Restore Habitat), which was determined as the most appropriate credit by *GB-CS Model* according to *the relative closeness* (Ci^+ =0.6636) and marked as "YES" according to *the evaluation scale* (see Table 4.4), has been already determined as "YES" in the original checklist applied in this residential GB project. This result ensures that the first criterion of model validation was accomplished.

The second criterion is that the least suitable credit(s) (i.e. the farthest alternative to the ideal solution) detected by the *GB-CS Model* should have been already determined as "NO" in the original checklist. The least suitable credit(s) is any credit which has the lowest C_i^+. This criterion provides help for examining the credit(s) which is/are out of the scope of this real project and was not implemented by the project teams, since the credit(s) marked as “NO” in the original checklist refers to the credit(s) which are out of scope of the project. According to the test and comparison results, the credit (i.e. Brownfield Development), which has been already determined as “NO” in the original checklist, was detected as the least suitable credit (Ci^+ =0.0877) by *GB-CS Model.* This result ensures that the second criterion of model validation was accomplished.

Similarly, the third criterion is that at least half of the credits which have been already marked as “NO” in the original checklist should match with the credits detected as “NO” by *the GB-CS Model*. Test and comparison results show that all the sixteen credits, whose C_i^+ are within the range of [0.00, 0.33), were detected as “NO” by *the GB-CS Model.* These sixteen credits match one-to-one with all credits that have been already determined as “NO” in the real checklist used in this residential project. This result ensures that the third criterion of model validation was achieved. Overlapping the credits detected as “NO” by *the GB-CS Model* with the credits marked as “NO” in the original checklist is highly important in verification of *the GB-CS Model*, since this result presents that this decision making support model can identify the credits which are out of the scope of the real project and not implemented by the project teams.

The fourth criterion is that at least half of the credits which have been already marked “YES” and/or “MAYBE” in the original checklist should be detected as “MAYBE” [0.33, 0.66) and/or “YES” [0.66, 1.00] by *the GB-CS Model*. This criterion provides help for determining the credits which are within the scope of this real project and have been implementing and/or have been implemented. The reason is that the credit marked as “YES” and “MAYBE” in the original LEED® checklist refers to the credits which are within scope of the project and are targeted to be fulfilled. Additionally, these credits help project teams meet with the Owner’s Project Requirements (OPR). In regard to the test and comparison results, all the five credits (i.e. Recycled Content, Water Efficient Landscaping, Material Reuse, Rapidly Renewable Materials and Construction IAQ Management Plan-Before Occupancy), which have been already determined as “MAYBE” in the original checklist applied in the case project, match one-to-one with credits detected as “MAYBE” [0.33, 0.66) by *the GB-CS Model.* All the remaining credits determined as "MAYBE" by *the GB-CS Model* have been already marked as "YES" in the original checklist of the case project. Matching all credits marked as "MAYBE" and/or "YES" in the original checklist with credits detected as "MAYBE" and/or "YES" by *the GB-CS Model* ensures that the fourth criterion of model validation was fulfilled. This result also presents that *the GB-CS Model* can determine the credits which are within the scope of the project, targeted to be obtained and have been implementing and/or already implemented by project teams.

According to the test and comparison results, all the credits detected as "YES", "MAYBE" and "NO" by *the GB-CS Model* match with the credits which have been already determined "YES", "MAYBE" and "NO" in the original checklist. Satisfying all the four criteria ensure that the *GB-CS Model* developed in this study was validated.

4.6 Discussions

The test and validation results present that TOPSIS detects appropriate credits among fifty four credits, i.e. alternatives, based on the particular attributes of GB project delivery (i.e. qualification and timing of involvement) using two types of inputs. These inputs are: (1) *relative weights* obtained by Delphi Method based weight assignment approach, and (2) *performance scores* given by the Sustainable Projects Coordinator (i.e. executive) to every team for every fifty four credits according to the three different scoring systems developed in this study (see Table 4.1-3).

When these two types of data are inputted in *the GB-CS Model*, TOPSIS provides two types of outputs which are (see Table 4.5): (1) *relative closeness* ($\boldsymbol{C_i^+}$) for every credit, (2) *preference order* of credits according to their relative closeness. In this study, preference order is the priority ranking list of credits where the GB certification credits are ranked from the highest to the lowest one according to their $\boldsymbol{C_i^+}$ attained by TOPSIS. *The highest relative closeness* (i.e. the closest alternative to the ideal solution) corresponds to *the most appropriate and resource efficient credit*, while *the lowest relative closeness* (i.e. the farthest alternative to the ideal solution) corresponds to *the least appropriate credit.*

Based on the relative closeness and ranking of the preference order, the most suitable and resource efficient credit detected is “Site Development-Protect and Restore Habitat”, whose *relative closeness* is 0.6636 for the residential project stated above (see Table 4.5-6). This credit was determined as “YES” according to the *evaluation scale* (see Table 4.4) since its C_i^+ is within the range of [0.66, 1.00]. Thirty seven credits including the prerequisites were detected as “MAYBE”, since their C_i^+ are within the range of [0.33, 0.66) for this case project. C_i^+ of the remaining sixteen credits are within the range of [0.00, 0.33); thereby these credits were detected as “NO”. *The relative closeness* values (C_i^+), which are lower than 0.66, indicate that this residential GB project and its project teams might not be sufficiently qualified to meet with the unique requirements of these credits and/or the project teams could not get involved or be planned to be involved in the process in a timely fashion. These results suggest that the particular attributes related to this project and its project teams (i.e. qualifications of project teams and timing of project teams’ involvement) need to be improved to efficiently fulfill the specific requirements of the credits detected as “MAYBE” and “NO” by *the GB-CS Model* according to the test results.

If the owner and/or owner’s representative of this LEED® registered residential project would (1) build the project teams with experienced personnel whose qualifications help for meeting with the requirements of the credits detected as “MAYBE” and “NO”, and (2) improve the project delivery process by early involvement of these qualified project teams, their qualification would drastically increase the design efficiency and prevent accumulation of excess time and costs in subsequent phases. If the owner address the credits with high relative closeness values (i.e. the closest alternatives to the ideal solution), they would allocate resources much more efficiently. The reason is that they could fulfill the requirements of these appropriate credits and related improvements. In this manner, they would not only achieve the targeted level of GB certificate but also meet the additional credit requirements in terms of design, construction and certification documentation with minimal waste of time, cost and labor.

These results show that *the GB-CS Model* allow to determine the GB certification credits that are more likely to be fulfilled by the particular attributes of GB project delivery, and to properly assess the current condition of project and project teams by examining hierarchically designed GB project delivery attributes and large amount of credits in a GB rating system. The results also present that this integrated decision making support model enable to proactively assist the owners in improving the existing attributes of GB project delivery (i.e. qualification and timing of involvement) to meet with the specific requirements of the credits detected as "MAYBE" (thirty seven credits) and "NO" (sixteen credits) according to *their relative closeness.*

4.7 Conclusions

This study explained in this chapter provides the second part of the ***G**reen **B**uilding-**C**redit **S**election (**GB-CS**) Model* that employs TOPSIS to determine the GB certification credits which suit the particular attributes of GB project delivery the most. This chapter presents the application, test and verification of this integrated decision making support model. This study provides a flowchart illustrating how this model would be used as guideline in selecting appropriate credits for GB certification and in assessing the existing situation of project and project team before deciding to follow a GB Rating System.

This multi-attribute decision making support model was developed from the hierarchical framework which is based on *the timing of project teams' involvement* and *qualifications of project teams*. Both of these GB project delivery attributes play a crucial role in the successful completion of GB projects by mitigating root causes leading to increased waste and decreasing associated waste as the findings of Chapter 2 illustrate.

The GB-CS Model is driven by the integrated use of Delphi Method based weight assignment approach and TOPSIS. Delphi Method provides researchers increased data quality by combining several experts' judgments and eliminating ambiguities and inconsistency while TOPSIS guarantees to detect the best alternative(s) among large number of alternatives. Hence, this multi-methodological decision making support model: (1) designates reliable relative weights obtained from GB experts by *Delphi Method based weight assignment approach* (see Chapter 3), and (2) detects appropriate and resource efficient GB certification credits based on GB project delivery attributes via *TOPSIS*. In this manner, this integrated approach brings GB experts' knowledge together with GB project delivery attributes.

In order to determine appropriate credits based on the GB project delivery attributes, TOPSIS utilizes two types of inputs which are: (1) *relative weights* obtained from Delphi Method based weight assignment process (see Table 3.2 in Chapter 3), and (2) *performance scores* given by decision makers (i.e. GC and/or PM and/or authorized personnel under PM) to the GB project delivery attributes. While the relative weights are pegged into the model as the constant numbers, performance scores changes when any of project team members changes in the team or when a new team member gets involved in that particular team. Thus, the current situation of a project and project teams can be proactively assessed by constructing decision matrixes with revised performance scores.

When this two types of date are inputted, TOPSIS provides (1) *relative closeness* (C_i^+) of every credit, (2) *preference order* of credits according to their relative closeness (ranking list of credits from the most the least suitable one). In addition to them, the output of *the GB-CS Model*, presents (3) *add first cost ratio information* for each credit, and (4) *green points* corresponding to every credit. Add first cost ratio information for each credit was drawn from earlier studies (GSA, 20004; Stegall, 2004). Green points corresponding to every credit were obtained from the LEED 2009® NC checklist. This output including four types of information will be considered by the owner and/or owner's representative(s), i.e. the end-user, to select appropriate credits to be efficiently and effectively met by the project and project teams to get sufficient points for GB certification and to achieve project objectives with minimal waste of time, cost and labor.

In the output, all the credits are represented as "YES", "MAYBE" and "NO" according to *the relative closeness* obtained by TOPSIS and evaluation scale developed in this study (see Table 4.4 and Table 4.6). This representation way help (1) bring relative closeness values (C_i^+) into conformity with LEED® checklist since credits are marked as "NO", "MAYBE" and "YES" in original LEED® checklist, and (2) make the preference order more understandable for owners to guide them in the selection of the suitable credits. Hence, the credits can be easily determined as "NO", "MAYBE" and "YES" in the LEED® checklist to be utilized in a real project.

Accordingly, the output from *the GB-CS Model* gives guidance about the appropriate sets of credits to be implemented in the effort of attaining different levels of GB certifications possible. If owner wants to seek higher level of GB certification, they can easily find which additional credits are more suitable to undertake by simply going down the credit ranking list developed for the whole GB rating system. All GB certification levels (i.e. Certified, Silver, Gold, and Platinum) are indicated in the output by corresponding appropriate credits (see Table 4.6).

The *GB-CS Model* was tested on a LEED® registered residential project by conducting a case study. According to test results, GB certification credits detected as "YES", "MAYBE" and "NO" by this integrated model match with the credits which have been already determined "YES", "MAYBE" and "NO" in the original checklist used as a road map in this real LEED® registered GB project. These results ensure that *the GB-CS Model* developed in this study was validated.

Test results ensure that *the GB-CS Model* determines the credit(s) (1) which is/are not implemented in the real project, and (2) which are within the scope of the real project and have been implementing and/or already implemented by the project teams. Results also show that the reasoning mechanism of *GB-CS Model* based on Delphi Method and TOPSIS provides for analyzing the limitations and advantages of the current GB project delivery attributes for each credit in the list of fifty four credits. In this manner, by the guidance from *the GB-CS Model*, the existing attributes of GB project delivery (i.e. qualification and timing of involvement) can be improved for satisfying the specific requirements of the credits detected as "MAYBE" (thirty seven credits) and "NO" (sixteen credits). The results provide that the *GB-CS Model* ensures the owners and/or owner's representative(s) meet the requirements of LEED® 2009 NC Rating System by undertaking specific GB certification credits determined by this integrated model.

Test results show that the *GB-CS Model* can be utilized in recently initiated and/or ongoing projects (1) whose project teams have been already built, and (2) whose project teams have not been built yet. If the owners use *the GB-CS Model* in a recently initiated and/or an ongoing project, they can examine the limitations and advantages of the existing project delivery attributes for every credit in the GB rating system. Once Owner's Project Objectives (OPR) include attaining credits that *the GB-*

CS Model deems less suitable, the owner and/or owner's representative is suggested to choose to employ new team member(s) who is/are sufficiently knowledgeable and experienced in those GB credit(s) to prevent any possible impediments occurred through the GB design, certification, and construction processes. On the other hand, if *the GB-CS Model* is utilized in projects whose project teams have not been built yet, this decision making model can be employed as a guideline in team building and timing of project teams' involvement. Indeed, the reasoning mechanism of this integrated model allows the GB executives to analyze the required education and experience levels for project teams in terms of each credit in the GB rating system (i.e. LEED® NC). Hence, the guidance from this integrated model enable them to build more efficient project teams which are more likely to be fulfilled in an efficient and effective manner the unique requirements of credits regarding the Owner's Project Requirements (OPR). Furthermore, this integrated model provides aid in getting involved the new personnel in the GB processes in a timely fashion. In this manner, this interconnected decision making support model can be beneficial for preventing disruptions and bottlenecks in GB project delivery process by proactively assisting the owners and/or owner's representative(s) in the selection of suitable credits to be efficiently met by the particular attributes of the GB project delivery. Thus, by the guidance from *the GB-CS Model*, they could adopt an effective course of action that would ensure them to mitigate root causes resulting increased waste through the GB project delivery process and to decrease associated hidden costs in GB projects whose owner intend to achieve a GB certificate. In this manner, this new approach would help for obtaining successful project outcomes in terms of time, cost and sustainability by minimizing waste generated to fulfill additional requirements of GB design, construction and certification.

The GB-CS Model can be utilized in many types of new construction projects including high rise residential buildings (i.e. 9 stories or more), offices, libraries, churches, hotels and government buildings, since fifty four credits under the fundamental categories of LEED® 2009 NC Rating System were integrated into the hierarchical framework which constitutes the basis of this multi-attribute decision making support model. *The GB-CS Model* is also relevant to researchers since this multi-methodological study establishes the prosperous use of the integration of Delphi Method based weight assignment with TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution). This integrated approach help researchers efficiently and effectively examine a large number of attributes and alternatives, in which the best alternative(s) is to be selected. The integrated use of Delphi Method and TOPSIS can be also adapted to other complex decision making problems which address the issue of selecting the best alternative(s) (i.e. credits) among many by considering multiple attributes (multiple criteria).

Following chapter (the Conclusion Chapter) summarizes the contributions of this Ph.D. Dissertation, and explains how they were validated and which tasks were performed to ensure data accuracy and quality. This final chapter also lists some possible future research areas.

References cited in this chapter:

Behzadian, M., Otaghsara, S.K., Yazdani, M. and Ignatius, J. (2012). "A state-of the-art survey of TOPSIS applications", *Experts Systems with Applications,* 39(17), 13051-13069.

Benayoun, R., Roy, B. and Sussman, N. (1966), "Manual de reference du programme electre", *Note de Synthese et Formaton, no. 25, Direction Scientifque SEMA,* Paris, France.

Dalkey, N.C., Rourke, D.L, and Snyder, D. (1972). *Studies in the quality of life,* LexingtonBooks, Lexington, Mass.

Hasson, F. and Keeney, S. (2011). "Enhancing rigour in the Delphi technique research." *Technological Forecasting & Social Change*, 78(9), 1695-1704.

Hwang, B.G. and Ng, W.J. (2013)."Project management knowledge and skills for green construction: Overcoming barriers." *Int . J. of Project Manage.*, 31(2), 272-284.

Hwang, C.L and Yoon, K. (1981). *Multiple Attribute Decision Making: Methods and Applications*. New York: Springer-Verlag.

Joshi, R., Banwet, D. K. and Shankar, R. (2011). "A Delphi-AHP-TOPSIS based benchmarking framework for performance improvement of a cold chain." *Expert Systems with Applications*, 38(8), 10170-10182.

Kasim, T., Li, H. and Rezgui, Y. (2012). BREEAM: Based Dynamic Sustainable Building Design Assessment. *EG-ICE 2012*, Munich, Germany,4-6 July 2012.

Kim, G., Park, C. S. and Yoon,K. P.(1997)."Identifying investment opportunities for advanced manufacturing systems with comparative-integrated performance measurement." *Int. J. of Production Economics,* 50 (1),23-33.

Milani, A. S., Shanian, A. and Madoliat, R. (2005). "The effect of normalization norms in multiple attribute decision making models: A case study in gear material selection." *Structural Multidisciplinary Optimization*, 29(4), 312-318.

Nijkamp, P., Rietvelt, P. and Voogd, H. (1990). *Multi-criteria evaluation in physical planning' Amsterdam: North-Holland*. Elsevier Science Publishers B.V., Amsterdam, The Netherlands.

Shih, H.-S., Shyur, H.-J. and Lee, E.S. (2007) "An extension of TOPSIS for group decision making", *Mathematical and Computer Modeling*, vol. 45, 801-813.

Stegall, N. (2004). "Cost implications of LEED Silver Certification for new house residence at Carnegie Mellon University".Senior Honors Research Project, Carnegie Inst. of Tech.

TOKI, 2014. Toplu Konut Idaresi Baskanligi, < http://www.toki.gov.tr/english/3.asp> (accessed Sep. 15, 2014)

Triantaphyllou, E. (2000), "Multi-Criteria Decision Making Methods: A Comparative Study", Kluwer Academic Publishers, The Netherlands.

USGBC (2009). U.S. Green Building Council. "LEED 2009 for New Construction and Major Renovations Rating System." <http://www.usgbc.org/resources/list/study-guides >, (accessed Feb.10,2014).

Weber, M. and Borcherding, K. (1993). "Behavioral influences on weight judgments in multi-attribute decision making." *European J. of Operational Research*, vol.67, 1-12.

Yuan, J., Skibniewski, M.J., Li, Q. and Zheng, Lei (2010). "Performance objectives selection model in public-private partnership project based on the perspective of stakeholders", *J. of Manage. Eng.*, 26(2), 89-104.

Yue, Z. (2011a). "An extended TOPSIS for determining weights of decision makers with interval numbers." *Knowledge-Based Systems*, 24(1), 146-153.

Yue, Z. (2011b). "A method for group decision-making based on determining weights of decision makers using TOPSIS", *Applied Mathematical Modeling*, 35(4), 1926-1936.

Yue, Z. (2012). "Extension of TOPSIS to determine weight of decision maker for group decision making problems with uncertain information", *Experts Systems with Applications*, 39(7), 6343-6350.

Zanakis, S.H., Solomon, A., Wishart, N. and Dublish, S.(1998). "Multi-attribute decision making: A simulation comparison of select methods", *European Journal of Operational Research*, 107(3), 507-529.

CHAPTER 5

CONCLUSIONS

In this research, I initially classified waste types and associated root causes, investigated their cause-effect relationship and ranked them according to their negative impacts on time and cost in design and construction phases of GB project delivery process by conducting a case study including three GB projects and a two-rounded Delphi Method. Drawing from my findings, I focused on two GB project delivery attributes, i.e. *timing of project teams' involvement and qualifications of project teams*, which play a crucial role for ensuring successful completion of GB projects while enduring minimal waste throughout GB project delivery process. Based on these two attributes, I built a hierarchical framework to assign relative weights to these attributes, and to constitute the basis of my decision making support model. I developed this hierarchical framework into *an integrated and highly structured decision making support model* for determining appropriate credits and resource efficient (i.e. time cost and labor) GB certification credits that suit these attributes the most. I tested and validated this multi-attribute decision making support model by performing a case study on a LEED® registered residential project which is one of three GB projects analyzed in this study.

The Green Building-Credit Selection (GB-CS) Model is a highly critical decision milestone in the pursuit of successful GB projects since working with properly selected GB certification credits in accordance with the particular attributes of GB project delivery would allow ensuring better outcomes from GB projects through the minimization of elevated waste generated to respond for the needs of GB design, construction and certification. The first part of *the GB-CS Model* employs Delphi Method that was combined with TDR method to designate relative weights to these GB project delivery attributes by using the hierarchical framework developed in this study. In the second part of *the GB-CS Model*, the Delphi Method-based weight assignment approach was combined with TOPSIS to determine appropriate credits in accordance with GB project delivery attributes. In this second part, TOPSIS utilizes (1) the relative weights obtained through Delphi Method based weight assignment process, and (2) performance scores given by the executive(s) to detect appropriate GB certification credits that suit the particular GB project delivery attributes the most. Adopting this type of a multi-methodological approach including both qualitative and quantitative analysis provides the fulfillment of my grand vision in a holistic perspective. In fact, engaging mix-methodologies ensures researchers to better examine such a complex phenomena (Leicht et al., 2010).

The reasoning mechanism of this multi-methodological approach, which was developed for determining appropriate for GB certification based on GB project delivery attributes, support the vision of developing "*an interconnected decision-making guideline*". In this vision, the output will be considered by the owner and/or owner's representative(s) (i.e. the end-user), to assess the particular conditions of the project and project team before deciding to follow a GB rating system and to select the GB certification credits that are more likely to be obtained in an efficient and effective manner considering the particular attributes of GB project delivery.

The following sections describe the contributions and corresponding validations, practical implications and recommended future research work.

5.1 Summary of Contributions and Validations

The first contribution of this research addressed the need for *"identification, classification and ranking of the waste types and related root causes occurred in design and construction phases of GB project delivery process"*. In order to decrease the waste and associated hidden costs in GB projects, and uncover the underlying reasons of prolonged durations, high costs and additional labor involved with GB projects, waste types in GB project delivery process and related root causes are needed to be identified and classified in detail.

When the waste types and related root causes were identified and classified for GB projects and ranked according to their negative effects on time and cost increases in GB project delivery process, it was observed that *"timing of project teams'* *involvement in GB processes"*, and *"qualification of project teams in GB features"* are the critical project delivery attributes for the minimization of waste and related root causes throughout GB project delivery process. Based on these two GB project delivery attributes, I built my decision making support model which was needed to be developed to provide guidance to the owners in the selection of credits that are more likely to be fulfilled in an efficient and effective manner by the attributes of project delivery to achieve GB certification within the allowed budget and time. According to the requirements and the reasoning mechanism of multi-attribute modeling, setting a hierarchical framework and assigning sensitive and reliable relative weights to these hierarchically designed attributes initially needed to be developed a multi-attribute decision making model (Triantaphyllou, 2000). The second, third and forth contributions of this research addressed these needs, respectively. The second contribution is "*development of a hierarchical framework based on the green building project delivery attributes and associated relative weights"*. The third contribution is "*an integrated decision making support model for based on green building project delivery attributes"* to determine appropriate credits for GB certification based on the particular attributes of project delivery. The forth contribution is "*the combined use of Delphi Method based weight assignment approach and TOPSIS to detect the best alternative(s) within a large set"*.

Each contribution, corresponding validation and specific tasks performed to ensure data reliability are further described in the following sections.

5.1.1 Contribution 1: Identification, Classification and Ranking of the Waste Types and Related Root Causes in Green Building Project Delivery Process

Previous research show that GB projects are generally more complex in comparison with the NGBs and have some specific types of waste due to their collaborative and interdisciplinary nature to respond to the needs of interconnected green design systems (Pulaski et al., 2003; Riley et al., 2004; Lapinsky at al., 2006;). However, research studies on waste in GB project delivery process are limited, and most of the previous studies that investigated waste types in construction industry addressed non-green building (NGB) projects (Koskela, 1992; Josephson, 1998; Simonsson et al., 2012). Only a small number of studies examined waste in GB project delivery process (Porter and van der Linde, 1995; Pulaski et al., 2003; Riley et al., 2004; Horman et al., 2006). Even though prior studies identify some waste types and related root causes for GB projects, a comprehensive identification and classification still remains to be a crucial necessity for the GB industry and GB literature. Hence, waste types in GB project delivery process and related root causes needed to be identified and classified to decrease the hidden costs, to uncover the underlying reasons of increased levels of time, cost and labor involved with the GB projects, and to motivate owners to invest in GB projects.

My research fulfills these gaps in the literature by examining waste and associated root causes in detail for GB project delivery. This study classifies the waste types and related root causes, investigates their cause-effect relationship and ranks them according to their negative impacts on time and cost in design and construction phases of GB project delivery process. This classification is presented on an Ishikawa diagram, which represents the cause-effect relationship between waste types and primary root causes consisting of secondary root causes (see Fig. 2.1).

A broad review of the literature from 1992 to 2013 has been initially undertaken by mapping the literature for identifying and classifying waste and related root causes throughout the GB project delivery process and revealing the cause-effect relationship between them. In order to mitigate subjectivity, certain procedures based on keywords were employed in selecting and investigating publications (Betts and Lansley, 1993). In this manner, a comparative analysis of the findings is more likely to be performed by employing a similar data selection approach and analysis constructs.

Publications uncovered during the literature review are from different sources including reviews, thesis, case study and survey / interviews. All these publications are international. The authors of these publications are not only academics but also practitioners that would (1) ensure multiplicity in the data gathered, (2) allow comparative analyses, (3) extend the research domain and (4) bring different perspectives together. In this manner, this pluralism would contribute to the development of this field.

With the same intention, a qualitative and observational case study was conducted to extend the results of the literature review and to perform an in-depth analysis. The case study includes three large scale GB projects of one general contractor, and data was collected using two methods: (1) Semi-structured interviews with five project team members, (2) participation at design coordination meetings that were performed biweekly/monthly by GB consultants, architects, civil engineers and engineers in a high performance (HP) green hospital project. Engaging such an observational case study ensures researchers to answer what phenomena occurred and why the phenomena occurred (Leicht et al., 2010). With the aim of identifying and classifying waste types, and related primary and secondary root causes in GB project delivery process, the findings from the literature review and case study were triangulated. Triangulating the findings of literature review and such a case study ensure (1) to better interpret the waste types and associated root causes, and (2) to reveal their relationship in a comprehensive perspective.

When the data from literature review and case study were triangulated, six common types of waste, and four primary root causes including sixteen secondary root causes were identified. These findings were illustrated on an Ishikawa diagram to represent the cause-effect relationship between waste and related primary root causes identifying secondary root causes. Ishikawa Diagram provides teams to focus on the problem itself and project teams to focus on the underlying reasons of the problem (Banawi, 2013). The results were represented to the interviewees for getting their feedback to validate the findings.

In order to rank the classified waste and associated root causes based on their negative effect on design and construction phases in GB project delivery process, a Delphi Method, which is an expert-oriented inquiry, was performed. In this method, panel members were asked to rank the list of waste types and related root causes in two rounds to assure that a consensus is reached, since two-rounded Delphi process provides researchers decrease biases in outputs and achieve consensus among panel members (Dalkey et al., 1972). Performing iterative rounds with qualified panel participants that is one of the important features of Delphi method, ensures researchers to obtain reliable and quantitative results via this problem-oriented mapping research method (Linstone and Turoff, 1975).

The other important feature of this particularly designed method is that Delphi Method provides researchers to obtain rational judgments from a preselected group of experts through series of questionnaires (Brown, 1968). With the intention to increase data accuracy and reliability, qualification criteria for panel members were determined to ensure that panel members attended to this Delphi process have sufficient knowledge and experience in the GB projects (Hallowell and Gambatese, 2010). It was expected that panel members meet at least one criterion from each of the following two groups: (1) knowledge/education level, (2) experience level. These qualification criteria were explained in detailed in Chapter 2. According to these criteria, twelve panel members, who are qualified in GBs and accredited by various areas of expertise, were selected (see Table 2.4). Carefully selecting panel participants based on these predefined qualification criteria provides that all panel members have sufficient knowledge and experience in the GBs.

With the aim of providing multiplicity in the outputs and combining experiences in different professional fields, panel participants were selected from different departments of the General Contractor Company and GB Consulting Companies working on these three GB projects which were investigated within the case study. GB Consultants involved in this Delphi Inquiry work on international GB projects. In this manner, data collected through this two-rounded Delphi Process would contribute to the development of this field.

In this research, while mean and median values were used for representing the central tendency (Dalkey, 1969, 1972), standard deviation (SD) was used for comparing the consensus at each round (Gunhan and Arditi, 2005a, b; Hallowell and Gambatese, 2010). SD was expected to decrease from one to the next round if the group consensus is achieved (Gunhan and Arditi, 2005b, Vidal et al., 2011). In the second round, SD values were lower compared to the first round and all SD values were less than 1. SD less than 1 indicates that a high level consensus was reached among panel members.

The waste types and root causes were ranked according to the associated mean value obtained from twelve experts in the second round. If mean values of two waste types or root causes are equal, median values were used for ranking. The ranking lists (see Table 2.5-.6) were represented to twelve panel members to validate the outputs. The priority ranking lists of waste and related root causes were verified by these twelve experts. This well-structured Delphi Process ensures researchers to attain highly reliable and accurate data.

My study presents that the priority ranking of waste types for design and construction phases greatly differs from each other except for the top ranked waste, *"defects/revision/reworks",* which is same for both the design and construction processes of GBs. "*Prolongation and overprocessing of design"* is the second most important waste for the design phase, while "*excessive documentation" is* for the construction phase. The reason of this difference might be that design teams should integrate all necessary GB specifications into the construction documentation, and they need to be compiled and submitted in full order. These three waste types underlined not only elongate activity durations but also lead to additional costs (i.e. hidden costs) to meet the mandatory requirements of GB projects and the owners' demands (Robichaud and Anantatmula, 2011; Shresta and Pushpala, 2012). The findings from the Delphi Method point out that the scores of most of the waste types in design phase are lower than that of waste types in construction. The reason might be that waste types occurred in design phase cascade down to the next phases.

The results present that the root causes related to GB project team attributes (i.e. "*lack of qualified project participants in "Green" concepts*", and *"failure in identification of stakeholders' requirements"*) gained higher points in design and construction phases compared to the root causes related to GB project attributes (i.e. *"ineffective project delivery, design, and management practices"*, and *"challenges in fulfilling sustainability requirements"*). "*Late involvement of key project participants in GB processes"* and *"integrating environmental matters into the design in late phases of the GB project"* are also the two highest scored secondary root causes for design and construction phases. While *"lack of educated key project team members experienced in GB projects"* is the third secondary root cause for design, *"lack of educated sub-contractors experienced in GB projects"* is the third root causes for construction. These findings point out that late involved project teams in GB processes and unqualified project teams in GB projects have considerable impact on waste generation in design and construction phases of GB project delivery process. Extensive discussions regarding the waste types and related root causes were hold in Chapter 2.

Consequently, my study identifies and classifies waste types and associated root causes for GB projects and ensures researchers and GB executives to realize the essential requirements for delivering GB projects while enduring minimal waste and thus ensuring successful project outcomes. The results of this research can be used for mitigating the underlying reasons of increased waste and minimizing the waste to decrease the hidden costs, and to motivate owners to invest in GB projects. Such an in depth examination of waste and related root causes in GB project delivery process provides for determining the particular project delivery attributes which crucially affect on the pursuit of GB projects with minimal time and cost related waste. Moreover, these findings can be engaged for developing tools and/or models for the owners that can proactively detect existing root causes and resulting waste in GB project delivery process and aid them in the selection of appropriate credits within GB rating systems for achieving GB certification with minimal waste.

5.1.2 Contribution 2: Development of Hierarchical Framework based on the Green Building Project Delivery Attributes and Associated Relative Weights

Some of the prior studies uncovered during the literature review investigated the required skills, knowledge and practices to deal with escalating difficulties at GB projects (Syal et al., 2007; Wu and Low, 2010; Robichaud and Anantatmula, 2011; Hwang and Ng, 2013). Some of these studies, on the other hand, addressed early involvement of project teams in the process of GB project delivery (Riley et al., 2005; Beheiry et al., 2006; Molenaar et al., 2010; Swarup et al., 2011). Although these studies emphasized the importance of these project delivery attributes to ensure the successful completion of GB projects, none of these studies addressed the necessity for examining the timing of project teams' involvement or the qualification of project teams in terms of their relative importance under a hierarchical framework considering multiple project teams. Moreover, examining project delivery attributes and their relative importance on the performance of the project by considering different types of buildings, and conducting in-depth analysis of certain case studies in different geographies and countries was needed for facilitating the successful delivery of GB projects (Gultekin et al., 2013).

My study addresses the need for establishing relative weights to *timing of project teams' involvement* and *qualification of project teams* which is analyzed with a hierarchical framework based on LEED® NC Rating System, that was developed through the use of Delphi Method based weight assignments approach conducted with GB experts accredited by US Green Building Council and/or UK Green Building Council. Designation of relative weights to the project delivery attributes by engaging such an integrated hierarchical framework that is structured under the light of LEED® NC Rating System ensures the examination of these attributes' importance levels for each credit and assignment of these attributes' relative weights in a holistic perspective. On this road, my study (1) sets a hierarchical framework based on the GB project delivery attributes (i.e. timing of project teams' involvement and qualification of project teams), (2) designates the importance levels to these hierarchically designed GB project delivery attributes by using the hierarchical framework in which credits under LEED® NC Rating System was integrated and (3) assigns relative weights to these hierarchical attributes based on their importance levels. In this manner, my study primarily engages this integrated approach to address the need for developing a multi-attribute decision making model that accommodates weighted analysis of importance levels for GB project delivery attributes. In fact, multi-attribute modeling requires first the building of a hierarchical framework, and second the assignment of relative weights to the hierarchically designed attributes (Triantaphyllou, 2000).

This integrated research provides a hierarchical framework based on GB project delivery attributes to designate their importance levels and assign their relative weights to be further inputted in TOPSIS which is utilized for determining appropriate GB credits in congruence with particular attributes of GB project delivery. This three tiered framework developed in this study is basically divided into two major GB project delivery attributes which are: (1) *timing of project teams' involvement in GB process* and (2) *qualification of project teams in GB project and features*. In the second level, there are six attributes (i.e. education, experience, involvement of Feasibility SD, DD, CA). Seven attributes (i.e. owner, general contractor, mechanical team, electrical team, architectural team, civil team, and material suppliers) exist within every secondary attribute (see Fig. 3.2).

This three tiered framework was built considering specifically for a Design-Build project since Design-Build Method, based on the integrated project delivery

(IPD) procedure, is strongly suggested to ensure the successful delivery of GB projects (Korkmaz et al., 2010). The IPD procedure promotes building integrated project teams that is indicated as the most important factor for the project success in terms of time, cost and sustainability (USGBC, 2009; Korkmaz et al., 2010; Robichaud and Anantatmula, 2011). Based on the integrated project team approach, seven types of *project teams* were introduced into the framework. Therefore, this hierarchically designed framework, which includes a broad range of project teams from different technical disciplines, provides the encouragement of interdisciplinary synergies (NCI, 2007). This hierarchically designed framework, based on the IPD procedure, will be the basis of studies which aim at developing tools and/or models for providing aid in the pursuit of successful GB projects by optimizing GB project delivery.

This hierarchical framework was advanced by integrating fifty four credits in LEED® 2009 NC under BD+C Rating System. This integrated framework was used in the Delphi Method based weight assignment process as the questionnaires. Integration of the credits under a GB rating system provides for the designation of relative weights to the hierarchically designed project delivery attributes by dealing with all environmental aspects of GB project requirements.

The fundamental criterion in the weight assignment procedure is to establish weights with high sensitivity and reliability (Nijkamp et al., 1990; Weber and Borcherding, 1993). With the aim of meeting this essential criterion, Delphi Method was engaged as the central step to this weight assignment approach since this expert oriented method held with high regards in the literature (1) to weight hierarchical goals and objectives, (2) to strengthen the weight elicitation procedure, (3) to derive reliable and sensitive relative weights, (4) to provide internal consistency, and (5) to decrease vulnerabilities in data (Dalkey et al., 1972; Linstone and Turoff, 1975; Emory and Cooper, 1991; Gunhan and Arditi, 2005a; Hilbert et al., 2009; Hasson and Keeney, 2011). In this weight assignment approach, Delphi Method was employed for deriving importance levels of GB project delivery attributes by using the hierarchical framework in which in which 54 green credits were integrated, while TDR was utilized to assign relative weights of these attributes by normalizing the importance levels.

Similar to the Delphi Inquiry performed in the previous step of my research, in order to increase data accuracy and quality, qualification criteria for panel members were determined to ensure that panel participants attended to this Delphi process have sufficient knowledge and experience in the GBs and GB certification. It was expected that experts meet at least one criterion from each of the following two groups: (1) knowledge/education level, (2) experience level. Based on these criteria, eleven experts were selected from different disciplines (i.e. GB consultants, academics and professionals) to provide multiplicity in the outputs and to combine experiences and knowledge of different fields. Panel participants with sufficient knowledge and experience in the GBs and GB certification ensure data accuracy, data quality and data reliability by minimizing possible biases.

With the intention to increase data reliability and to decrease possible biases in the outputs, a two-rounded Delphi Method was employed same as before performing to rank the waste types and related root causes. In the first round, mean value and SD were calculated to present the statistical group response of eleven panel members (Geist, 2010). In the second round, trimmed mean and SD for each first, second and third level attributes were re-calculated based on points given by ten among eleven panel members. Calculating trimmed mean value in the last round of Delphi Process is suggested as the best technique, since it eliminates biased responses of the panel members, which can alter mean values (Rowe and Wright, 2001), by ignoring the outliers (Cha and O'Connor, 2005; Hallowell and Gambatese, 2010).

This procedure is required to eliminate bias in the results of Delphi process which is attained from processing large amount of numerical data gathered from experts. This barrier was overcome by calculating trimmed mean value in the second round of Delphi Process. This strategy provides that decrease rate in SD values from first to second round is between 52%-82%. This output indicates that consensus was built among GB experts, and possible biases and inaccuracies in data were minimized. This high decrease rate in SD values is appreciable since a large amount of data (i.e. six 54x7 matrix, two 1x2 matrix and one 1x4 matrix formatted questionnaires) was gathered from experts in two rounds. The results prove that calculating trimmed mean values in the second round of Delphi Process ensures researchers to decrease possible biases and shortcomings in the data gathered from panel participants through series of questionnaires.

Completing each questionnaire was a detail-oriented and time consuming activity; thereby, experts were given four to six weeks in each round to fill out questionnaires. Carefully selecting experts and allowing enough time for them to provide feedbacks for this compelling Delphi Process, strengthens the Delphi Process and eliminates the risk of possible inaccuracies and biases which could happen while processing large amounts of data. Thus, this strategy ensures the achievement of more reliable and accurate data from panel members. Accomplishment of this Delphi Inquiry is highly valuable for the literature since every GB expert intentionally contributed in this laborious Delphi Process lasted six months.

This two-rounded Delphi Method provides the importance levels (trimmed mean values) for hierarchically designed attributes in terms of LEED® 2009 NC Rating System (see Appendix A). This procedure ensures that the importance levels of each attribute were validated by eleven GB experts. Outputs attained by this expert-oriented qualitative methodology do not need to be test-retested to control the reliability of data (Okoli and Pawlowski, 2004; Hasson and Keeney, 2011), because the reasoning mechanism of Delphi Method is particularly designed to ensure higher reliability, accuracy and quality in outputs by minimizing possible biases. Delphi Method achieves such good results as it commands to perform iterative rounds and provides controlled feedbacks from experts (Mitchell, 1991; Rowe et al., 1991).

This two-rounded Delphi Method was combined with TDR method to assign relative weights to the attributes, since such a huge amount of data sets should be normalized to be further utilized in a multi-attribute decision making (MADM) method as inputs. Based on the requirements of multi-attribute (i.e. multi-criteria) analysis, it was expected that the sum relative weights should be equal to one within individual groups and also the relative weight of the whole system should equate to one since these attributes were hierarchically set. Meeting this fundamental criterion allow researchers to use these relative weights as inputs in MADM methods (i.e. TOPSIS) that are engaged in decision making models.

This integrated weight elicitation approach provides two first level weights regarding the primary attributes, six second level weights regarding the secondary attributes and forty two third level weights regarding the tertiary attributes. The sum first, second and third level weights are equal to one within those particular groups, respectively. The relative weight of the whole system also equates to one; hence these relative weights can be used in MADM methods as inputs. Furthermore, these relative weights will be beneficial for researchers whose purpose is to obtain better outcomes from GB projects through the optimization of GB project delivery.

Results ensure that Delphi Method based weight assignment approach allows researchers to designate reliable and sensitive relative weights to hierarchically designed attributes that can be used in MADM analysis. The details of this methodology and tasks performed to increase reliability and accuracy in the outputs was explained in Chapter 3.

My study presents invaluable information to the GB Executives in the form of quantitative data obtained from highly qualified eleven GB experts regarding the importance of "*timing of project teams' involvement in GB processes*" and *"qualification of project teams in GBs".* First level weights show that these attributes are interconnected variables and cannot be considered separately in the effort to optimize GB project delivery while enduring minimal waste of time, cost and labor.

In a similar manner, second level weights regarding *"qualification of project teams"* show that "*experience"* and *"education*" (i.e. professional accreditation, academic degree) support each other in the process of delivering GB projects which seek GB certification. Findings provide that project teams with high level of experiences and education in GBs and GB rating systems are needed to fulfill owner's project requirements and GB certification credits' requirements with minimal wasteful activities. Second levels weights regarding the "*timing of project teams' involvement*" present that GB project delivery is principally design driven. The findings of my study also suggest that early integration of GB features into the design phase would ensure the minimization of possible time-consuming and costly disruptions such as numerous change orders and reworks.

Third level weights show that the owner and architectural team play a crucial role in the completion of GB projects with high level of certificate on time and within budget. The reason is that, *the owner* directs the whole GB project delivery towards their project objectives, while "*architectural team"* transfers Owner's Project Objectives (OPR), "green" measures, GB credits' and certification requirements into the design. Extensive discussions regarding the relative impacts of primary, secondary and tertiary GB project delivery attributes on phases of GB project delivery process were hold in Chapter 3.

The findings of this laborious study can be used for providing aid in the optimization of GB project delivery and successful completion of GB projects by achieving project objectives within foreseen time and expenditures. Relative weights of hierarchically designed GB project delivery attributes can be used in MADM models which address the need for determining appropriate credits for GB certification based on the particular attributes of GB project delivery.

5.1.3 Contribution 3: An Integrated Decision Making Support Model Based on Green Building Project Delivery Attributes

Previous studies show that if selected GB certification credits are not suitable for the existing attributes of GB project delivery team, elevated levels of time, money and labor could get wasted while attempting to fulfill the additional requirements of GB design, construction and certification (Cassidy, 2003; Sprau, 2009; Robichaud and Anantatmula, 2011; Banawi, 2013; Gultekin et al., 2013). Hence, there was an obvious need for having a decision-making model that would tackle the complexities of GB projects and provide guidance for determining appropriate GB certification credits in congruence with the existing project delivery attributes; however, such an integrated model was absent in the GB industry and literature. This type of guideline was a crucial necessity for the optimization of GB project delivery and completion of GB projects with successful outcomes in terms of time, cost and sustainability.

My research study addresses this necessity by developing a multi-attribute decision making support model to determine the GB certification credits that suit the particular GB project delivery attributes the most. This integrated model developed in this Ph.D. research provide the owner and owner's representative assess the existing situation of project and project team before making decisions to follow a GB rating system. This integrated decision making support, called *GB-CS*

Model, model was developed from the hierarchical framework in which fifty four credits categorized under LEED® 2009 NC within LEED® BD+C were integrated.

The GB-CS Model based on the particular attributes of GB project delivery, i.e. *timing of project teams' involvement and qualifications of project teams*, is driven by the integrated use of Delphi Method based weight assignment and TOPSIS. This multi-methodological decision making support model ensure researchers: (1) to designate reliable relative weights gathered from experts through *Delphi Method based weight assignment process*, and (2) to determine appropriate and resource efficient credits in accordance with GB project delivery attributes via *TOPSIS*. *The GB-CS Model* was tested and validated by conducting a case study on a LEED® registered residential project which is one of three GB projects investigated in the previous steps of this integrated research.

In this approach, the reasoning mechanism of TOPSIS allow the detection of appropriate credits within fifty four credits, i.e. alternatives, in accordance with the particular attributes of GB project delivery by using two types of inputs which are: (1) *relative weights* obtained through Delphi Method based weight assignment process, and (2*) performance scores* given by GC and/or PM and/or authorized personnel under PM (i.e. the secondary user(s)) to the GB project delivery attributes (i.e. qualification of project teams and timing of seven project teams' involvement). *Relative weights* are inputted into TOPSIS as constant numbers. *Performance scores*, on the other hand, can be changed when any of project team members change in the team or when a new team member is hired and get involved in the team.

The task of the secondary users (i.e. PM, GC) is to examine the consistency between the levels of project teams related GB project delivery attributes, the intended GB rating system and the credits categorized under the GB rating system by using *the GB-CS Model*. In this case study, performance scores were given by the Sustainable Projects Coordinator (i.e. an executive under PM) to the project delivery attributes for each fifty four credits in regard to three different scoring systems developed in this study (i.e. scoring systems regarding the (1) experience of project teams in GB features, (2) education of project teams in GB features, and (3) timing of project teams' involvement in GB processes) (see Table 4.1-3 in Chapter 4). Decision matrixes were constructed by these performance scores.

Performance scores of each attribute given for each credit refer the average score of regarding the team. It is expected that, the executive(s) will evaluate their team members separately for all different aspects (i.e. involvement, education, experience) and derive an average score for their team for every fifty four credits according to the scoring systems regarding the involvement, education and experience of every team member.

These performance scores will be inputted into the multi-attribute based decision making system as the overall score of that particular executive to construct decision matrixes. It is expected that when a new team member get involved in the process, the secondary users will re-construct decision matrixes with revised performance scores to proactively assess the current situation of project and project teams.

When these two types of data were inputted, four types of data were obtained from *the GB-CS Model*. The output attained from *the GB-CS Model* included (Table 4.5): (1) *relative closeness* (C_i^+) for every credit, (2) *preference order* of credits (i.e. ranking list of credits from the most the least suitable one) according to their relative closeness, (3) *added first cost ratio* for each credit and (4) *green points* corresponding to each credit. The first two data were attained via TOPSIS, the third data were gathered from earlier studies (GSA, 20004; Stegall, 2004), and the forth data was obtained from the LEED® 2009 NC checklist.

In order to provide the users (i.e. the owner, GC, PM) of *GB-CS Model* additional insight into how much financial load each of the LEED credits would introduce to the project, *"Added Cost Ratio"* was provided which equals to the ratio of *"Added Cost of a Credit"* to the *"Total Cost of the Project"* (see Table 4.6). Integration of additional cost ratio regarding each credit would enable estimate the approximate costs associated with project improvements to attain the credits within the predetermined limits of the budget while minimizing possible unforeseen expenditures connected with the pursued LEED credits.

The output represents all the credits which were detected and marked by *the GB-CS Model* as “YES”, “MAYBE” and “NO” according to their relative closeness and evaluation scale developed in this study (see Table 4.4-5-6). The aim of this representation way is (1) to bring *relative closeness* values (C_i^+) into conformity with LEED® checklist since credits are marked as "NO", "MAYBE" and "YES" in original LEED® checklist, and (2) to make *the preference order* (i.e. ranking list of credits) more understandable for owners to assist them in the selection of suitable credits for GB certification. In this manner, the credits can be easily marked as "NO", "MAYBE" and "YES" in the LEED® checklist to be utilized in a real project.

Once the owner focus on the credits with high relative closeness values (i.e. the closest alternatives to the ideal solution), they would allocate resources (i.e. time, cost, labor) much more efficiently as they respond to the requirements of these appropriate credits and related improvements. Owner would be able to achieve the targeted level of GB certificate and meet the additional credit requirements in terms of design, construction and certification documentation with minimal waste.

In the output, all certification levels (i.e. Certified, Silver, Gold, and Platinum) in LEED® Certification Program are indicated by corresponding appropriate credits according to the ranking list of credits attained via TOPSIS (see Table 4.6). Thus, the output from *the GB-CS Model* gives guidance about the appropriate sets of credits to be implemented in the effort of attaining different levels of GB certifications possible. Accordingly, if owner wants to seek higher level of GB certification, they can easily find which additional credits are more suitable to undertake by simply going down the credit ranking list developed for the whole GB rating system.

With the aim of validating *the GB-CS Model* and determining the similarities and differences between the credits attained from the *Model* and credits in the original checklist utilized in this LEED® registered residential GB project, I compared the credits detected as "YES","MAYBE" and "NO" by *the GB-CS Model* with the credits that have been already marked as "YES","MAYBE" and "NO" in the real checklist. I determined four criteria for comparing the credits and for examining the similarities and differences between them. It was expected that at least two of these four criteria should be fulfilled to validate *the GB-CS Model*. Details of these four criteria were described in Chapter 4.

Test and comparison results present that all the credits detected as "YES", "MAYBE" and "NO" by *the GB-CS Model* match with all the credits which have been already determined “YES”, “MAYBE” and “NO” in the original checklist used in this LEED® registered residential project. These results show that all the four criteria predefined for model validation were satisfied. According to these test and comparison results, *the GB-CS Model* developed in this study was validated.

The results of my research provide that *the GB-CS Model* can identify the credit(s) (1) which are out of the scope of the project and not implemented by project teams, and (2) which are within the scope of the project and have been implementing and/or already implemented by the project teams. The details of TOPSIS application and test results were given in Chapter 4.

Test results prove that *the GB-CS Model* determines the most appropriate and resource efficient GB certification credits that suit the particular GB project delivery attributes. Findings provide that this multi-attribute decision making support model brings GB experts’ knowledge together with current project delivery attributes. According to the test results, this interconnected and highly structured decision making guideline ensures that the owners and/or owner’s representative(s) fulfill the requirements of LEED® 2009 NC Rating System by undertaking specific GB certification credits determined by *the Model.*

As a consequence, *the GB-CS Model* allows the owner and/or owner’s representative assess the particular conditions of the project and project team before deciding on a GB rating system and selecting the appropriate GB certification credits. *The GB-CS Model* allows for the utilization of existing attributes of project delivery in an efficient and effective manner and ensures successful outcomes for GB projects pursuing certificate. Correspondingly, this integrated decision making support model provides proactive guidance for more efficient team building and timely involvement of project teams in order to deliver GB projects successfully. *The GB-CS Model* supports GB executives (i.e. PM, GC) minimize the underlying reasons of increased waste and associated high levels of time, money and labor spent for additional GB project requirements in terms of design, construction and certification.

5.1.4 Contribution 4: The Combined Use of Delphi Method-based Weight Assignment Approach and TOPSIS to Detect the Best Alternative(s) within a Large Set

This Ph.D. research presents the combined use of Delphi Method, TDR and TOPSIS that altogether constitute the reasoning mechanism of my integrated decision making support model, *the GB-CS Model*. In this multi-methodological approach, Delphi Method was employed to ascertain importance levels of GB project delivery attributes via expert opinion. TDR was used for designating relative weights of these attributes by normalizing the importance levels to be inputted in TOPSIS as the constant numbers. TOPSIS, which is the MADM method, was engaged to determine the GB certification credits that suit the particular GB project delivery attributes the most.

The advantage of this integrated approach is determining the relative weights that are required by TOPSIS via Delphi Method based weight assignment approach. If Delphi Method based weight assignment approach is not employed before TOPSIS, the relative weights would be given by DMs (i.e. user) and this might decrease the data accuracy. However, as previously mentioned, weights should be sensitive and reliable, which is the essential criterion in multi-attribute analysis (Nijkamp, 1990; Weber and Borcherding, 1993). In fact, more sensitive outputs are obtained from the weight elicitation approach, and more accurate results are attained from MCDM analysis, which is used for selecting the more appropriate credit for GB certification. On this road, this fundamental criterion for multi-attribute analysis was fulfilled by engaging a Delphi Method based weight assignment approach before TOPSIS. The reasoning mechanism of Delphi Method based weight assignment approach ensures researchers to achieve increased data quality by combining several experts' judgments and eliminating ambiguities and to derive reliable and sensitive relative weights for hierarchically designed multi-attributes that can be inserted in a multi-criteria decision making model. The reasoning mechanism of TOPSIS guarantees researchers to detect the best alternative(s) within a large number of alternatives. As I stated in previous section, this robust approach, based on Delphi Method and TOPSIS, was tested and validated on a LEED® residential GB project.

Integration of Delphi Method based weight assignment approach with TOPSIS help researchers examine in an efficient and effective manner a large number of attributes (i.e. criteria) and alternatives, in which the best alternative(s) is to be selected. In the studies that intend to select the best or the most appropriate alternative(s) within a large number of alternatives considering multiple attributes, this prosperous use of Delphi Method based weight assignment and TOPSIS can be adapted to solve other complex decision making problems. This multi-methodological approach ensures researchers analyze in a more excellent manner this type of convoluted phenomena (Leicht et al., 2010).

5.2 Practical Implications

This Ph.D. research endeavors to give the GB literature and GB industry the upper hand by providing invaluable information for improving GB project delivery process and achieving better outcomes from GB projects pursuing GB certificate. This multi-methodological study formalizes the identification and classification of waste and related root causes, and the presentation of cause-effect relationship between them, which altogether allow to develop a multi-attribute decision making support model for determining appropriate GB certification credits that are more likely obtained with the current attributes of GB project delivery while enduring minimal waste generated during the fulfillment of the additional requirements of GB design, construction and certification.

This new approach would provide aid in ensuring better project outcomes through the minimization of waste and associated hidden costs generated to fulfill additional requirements of GB projects. It is expected that the owners will utilize this interconnected decision making support model, called *GB-CS Model*, to assess the existing situation of their GB projects and project teams before deciding to follow a GB rating system and to select appropriate GB certification credits that are more likely to be met by the particular attributes of GB project delivery.

The GB-CS Model was developed based on LEED® 2009 NC under BD+C Rating System; thereby, the owners of new construction projects including high rise residential buildings (i.e. 9 stories or more), offices, libraries, churches, hotels and government buildings can utilize *the GB-CS Model* as a decision making guideline.

The GB-CS Model can be applied on recently initiated and/or ongoing projects (1) whose project teams have been already built, and (2) whose project teams have not been built. If *the GB-CS Model* is utilized in a recently initiated and/or an ongoing project and the Owner's Project Objectives (OPR) include attaining credits that *GB-CS Model* deems less suitable, the owner can choose to hire new team member(s) who have adequate education and experience in those particular credit(s).

If *the GB-CS Model* is implemented on a project where teams are yet to be build, guidance received from this integrated model would not only allow compiling more efficient project teams consisting of personnel who are sufficiently qualified on the specific requirements of targeted credits, but also allow those personnel to get involved in the GB processes in a timely fashion. Hence, in both situations, the owner can adopt an effective course of action considering the output attained by *the GB-CS Model* that would help them prevent any possible impediments through the GB design, certification, and implementation of credits' requirements on site. Correspondingly, the guidance from *the GB-CS Model* would allow them to mitigate the root causes that lead to increased waste throughout GB project delivery process and to ensure successful completion of project in terms of time, cost and sustainability.

The findings of this integrated study show that highly qualified project teams are greatly needed to convey properly OPR, GB features and the specific requirements of GB certification credits in design and construction phases of GB project delivery process to effectively eliminate any possible wasteful activities that elevate the hidden costs. In fact, the majority of hidden costs that stem from lower productivity and additional time spent for reworks can be attributed to waste in the processes (Porter and van der Linde, 1995; Pulaski et al., 2003; Riley et al., 2004). The study conducted by Cassidy (2003) shows that hiring an experienced MEP Team in GB projects allow minimizing 10% of the MEP construction costs (Cassidy, 2003).

The results of my study present that early integration of GB features into the design phase would allow the mitigation of possible time-consuming and costly disruptions that the project might incur in further stages of the GB project delivery, particularly, in construction phase through numerous change orders and reworks. The reason is that, late involvement of project teams would create greater complexities for the integration of the OPR into the site selection, SD, opening budget and schedule forecasts which would effectively lead to increased costs and time to complete GB Projects (Bogenstätter, 2000). Using integrated project delivery (IPD) methods (i.e. Design-Build), building information modeling (BIM) and advanced document management tools will ensure early involvement of project teams and, accordingly, early integration of environmental aspects into the GB project delivery process.

My findings suggest that, if the higher qualified project teams get involved in the GB project delivery at early stages, GB projects will incur less waste of time, cost and labor. In the contrary case, higher premium costs for GB projects will be resulted (Riley, 2009). Hence, my study show that (1) timely involvement of project teams, and (2) sufficiently educated project teams who are experienced in GB projects, particularly, GB projects pursuing GB certifications, are strongly required to decrease the hidden costs and to ensure the completion of GB projects with a high level of certificate on time and within budget. Missing one of these two major GB project delivery attributes would effectively mean that the whole mechanism is missing a critical piece of cogwheel which in return would lead to time-consuming and costly disruptions in the GB project delivery process that might prevent the fulfillment of GB certification and project objectives within foreseen time and expenditures. In fact, *GB-CS Model* provides guidance for the accomplishment of GB projects with high level of certification that are completed on time and within budget by decreasing elevated waste and associated hidden costs throughout the process of GB project delivery.

5.3 Recommended Future Research

This dissertation describes the development of an interconnected and highly structured decision making support model to determine appropriate and resource efficient GB certification credits in accordance with the particular attributes of GB project delivery with the overall intention to ensure the successful completion of GB projects by facilitating the optimization of GB project delivery. However, not all aspects of multi-attribute model development, application and outcome monitoring can be covered in one dissertation. The following research directions for future work are identified as possible extensions of the work described in this research.

5.3.1 Streamlining Green Building Project Delivery Process by Reduction of Waste and Related Root Causes

Focusing on proactively detection and elimination of waste and related root causes

In this research, I identified six types of waste, and four primary root causes including sixteen secondary root causes. The next step is to minimize these identified waste types and related root causes by streamlining the GB processes for decreasing associated hidden costs and for motivating owners to invest in GB projects. A promising future direction would be developing tools based on the project delivery attributes for the owners and/or owners' representatives that can proactively detect existing root causes and resulting waste in phases of GB project delivery process.

Focusing on assessing the effects of *the GB-CS Model*

In this study, I developed an integrated decision making support model, namely *the GB-CS Model*, for determining appropriate GB certification credits that are more likely to be fulfilled in an efficient and effective manner by the particular attributes of GB project delivery (i.e. timing of project teams' involvement and qualification of project teams). This interconnected model, which was tested on a LEED® registered GB project, assists the GB executives proactively regarding (1) how to put together more efficient project teams, (2) determine the timing of teams' involvement and (3) determine the most appropriate GB certification credits that suit the particular attributes of GB project delivery. The next step is to utilize *the GB-CS Model* as a decision making guideline in the selection of GB certification credits introduced at the beginning of a project and improve the project teams' composition with the guidance received from this interconnected model. Then, the appropriate credits detected by *the GB-CS Model* in early phases of the project will be compared with the credits actually fulfilled at the end of the project. The subsequent step is to monitor the outcomes of the GB project in which *the GB-CS Model* is utilized, and assess the relative effects of its usage on the minimization of waste by analyzing added time and cost that commonly stem from limited qualifications and late involvement of project teams. This interconnected model would be engaged in a vast number of projects for gathering credit specific statistical data to analyze the relative effects of its usage in terms of added time and cost.

5.3.2 Extending the Scope of Multi-Attribute Decision Making Support Model

Focusing on adapting the integrated approach of Delphi Method based weight assignment and TOPSIS for other decision making purposes

The reasoning mechanism of *the GB-CS Model*, based on the integrated approach of Delphi Method and TOPSIS, examines large number of attributes (i.e. criteria) and alternatives (i.e. credits for GB certification), in which the best alternative(s) is to be selected. A promising future direction would be employing this prosperous approach for other multi-attribute decision making purposes which address the issue of selecting the best or the most appropriate alternative(s) considering multiple attributes to deal with complex decision making problems.

Focusing on extending the reasoning mechanism of *the GB-CS Model*

The GB-CS Model engages TOPSIS as the multi-attribute decision making method to determine appropriate GB certification credits that suit the particular attributes of GB project delivery the most. In this study, in order to construct decision matrixes to perform multi-attribute analysis, performance scores were given by an executive (i.e. the Sustainable Projects Coordinator) to the GB project delivery attributes for each fifty four credits by using three different scoring systems. The next step is to extend the reasoning mechanism of this decision making support model to conveniently and effectively deal with group decision making problems by expanding the reasoning mechanism of TOPSIS since decision making processes in GB construction industry often include multiple decision makers (DMs). In fact, TOPSIS enable researchers examine complex group decision making problems (Yue et al., 2012). In this direction, the next step is to build the decision matrixes by inserting performance scores given multiple executives (i.e. DMs) of a project and analyzing weights of DMs by using TOPSIS.

Focusing on extending the scope of the hierarchical framework

I built the hierarchical framework based on the integrated project delivery (IPD) and integrated project team approaches that are strongly recommended to ensure the successful completion of GB projects (Korkmaz et al., 2010). Hence, I integrated seven types of project teams (i.e. owner, general contractor, architectural team, mechanical team, electrical team, civil team, material suppliers) into the framework under every secondary attribute. The next step is to extend the scope of this hierarchical framework by detailing the types of project teams, and providing detailed analysis for different types of project teams. On this road, the GB Consultant and/or Commissioning Agent could be integrated into this three tiered framework.

Another future direction would be advancing this hierarchically designed framework by integrating other attributes of project delivery such as the schedule performance regarding delivery speed, schedule growth and construction speed.

Focusing on developing the hierarchical framework into a decision making tool

This hierarchically designed framework based on the GB project delivery attributes would be developing into proactive decision making tools for the owners and/or owners' representatives to provide them aid in the pursuit of successful GB projects towards the IPD procedure.

Focusing on adapting *the GB-CS Model* for other GB Rating Systems

The *GB-CS Model* addresses LEED® NC under BD+C Rating System since this rating system is widely practiced (Syal et al., 2077; Wu and Low, 2010) and designed for adopting in many types of buildings (e.g. residential buildings, offices, hotels, governmental buildings) (USGBC, 2014). The reasoning mechanism of *GB-CS Model* allows researchers to adapt this interconnected model for different GB rating systems. The next step is to adapt this decision making guideline for other rating systems under LEED® Certification Program (e.g. Homes, BD+C (Schools, Healthcare etc.)) to use *the GB-CS Model* in different types of projects such as hospitals, schools, residential buildings with one to eight stories. The subsequent step is to adapt this integrated model for LEED® v4 to utilize *the GB-CS Model* in GB projects pursuing LEED® v4. A future direction would be adapting *the GB-CS Model* for different GB rating systems such as BREEAM® to utilize this guideline in much more GB projects.

5.3.3 Developing the Green Building-Credit Selection Model into an Effective Decision Making Tool

Focusing on integrating additional cost information of each credit

My observation during the case study and literature review showed that added cost information regarding each credit in a LEED® Rating System is limited in GB literature. For this reason, added cost information (i.e. *"Added Cost Ratio"*) that I integrated into *the GB-CS Model*, was gathered from prior studies addressing this issue (Stegall, 2004; GSA, 2004). On the road of developing *the GB-CS Model* into an effective decision making tool, a future direction would be advancing this decision making support model by the integration of *"Added Cost Ratio"* regarding each credit. The next step for upgrading this model is to examine added cost ratio for every credit implemented on a LEED® Platinum certified project, since it is the highest certification level in LEED® Rating System which requires fulfilling more than 75-80% of the credits and attaining at least +80 points over 110 points.

Moreover, separately examining the soft costs and hard costs spent for achieving each credit in a LEED® Platinum certified project could be suggested as a promising next step in the future development of this Model. Integration of *"Added Cost Ratio"* determined particularly for the soft costs and hard costs, would ensure the owners and/or owners' representatives to perform more realistic cost analysis regarding the specific requirements of each credit and features of GB project delivery and allow them to achieve the project objectives without enduring additional hidden costs.

Focusing on conducting with information systems

The reasoning mechanism of *the GB-CS Model* is based on advanced mathematical modeling since it engages the integrated approach of Delphi Method and TOPSIS. In this manner, a promising future direction would be combining this interconnected decision making support model with Building Information Modeling (BIM) systems to provide help for integrating effectively and efficiently GB features into the early stages of design process. This in return would allow decreasing waste that are mostly generated in design phase and cascade down to the next phases of GB project delivery process.

This integrated Ph.D. study formalizes the identification and classification of process waste with their related root causes for GB projects and reveals the cause-effect relationship between them which come together as a multi-attribute decision making support model that aid the optimization of GB project delivery and allows obtaining better outcomes from GB projects through minimizing the root causes of elevated waste and mitigating associated hidden costs. This multi-attribute model provides an interconnected decision making guideline which assesses the particular conditions of the project and project team before deciding to follow a GB rating system and determines the appropriate GB certification credits that are more likely to be obtained in an efficient and effective manner considering the particular attributes of GB project delivery. Properly selected GB certification credits would optimize GB project delivery by mitigating the excess levels of waste generated to fulfill the additional requirements of GB design, construction and certification. *The GB-CS Model* proposes to give the GB industry and literature the upper hand by facilitating GB project delivery with an adaptive guidance model that quantifies the outcomes of Green decisions and ensures the successful completion of GB projects.

In this chapter, I summarized the contributions of this Ph.D. Dissertation, and explained how they were validated and which tasks were performed to ensure data accuracy and quality. I also described four main research directions that are promising next steps for the successful completion of GB projects through the optimization of GB project delivery process.

Future research in these areas would extend current knowledge about developing multi-attribute decision making models for providing aid in the optimization of GB project delivery by decreasing waste in GB processes.

References cited in this chapter:

Banawi, A.A. (2013) “Improving Construction Processes by Integrating Lean, Green, and Six-Sigma” Improving Construction Processes by Integrating Lean, Green, and Six-Sigma”. PhD Dissertation. Department of Civil and Environmental Engineering. University of Pittsburgh.

Beheiry, S. M. A., Chong, W. K. and Has, C. T. (2006). “Examining the business impact of owner commitment to sustainability.” *J. Constr. Eng. Manage.,* 132(4), 384-392.

Betts, M. and Lansley, P. (1993), “Construction Management and Economics: a review of the first ten years”, *Construction Management and Economics,* 11(4), pp. 221–45.

Bogestätter, U. (2000). “Prediction and optimization of life-cycle costs in early design.” *Build. Res. Inf.,* 28(5/6) 376-386.

Brown, B. (1968). *A methodology used for the elicitation of opinions of experts*, The Rand Corporation, Santa Monica, Calif.

Cassidy, R., ed. (2003). “White paper on sustainability: a report on the green building movement” Building Design & Construction.

Cha, H.S. and O’Connor, J.T. (2005).”Optimizing implementation of value management processes for capital projects.” *J. Constr. Eng. Manage.,* 131(2), 239-251.

Dalkey, N.C. (1969). “*The Delphi method: an experimental study of Group opinion*”, Santa Monica, CA: The RAND Corporation, 1-18.

Dalkey, N.C., Rourke, D.L, and Snyder, D. (1972). Studies in the quality of life, LexingtonBooks, Lexington, Mass.

Geist, M.R. (2010). “Using the Delphi method to engage stakeholders: A comparison of two studies.” *Evaluation and Program Planning*, 33 (2010), 147-154.

Gultekin, P., Mollaoglu-Korkmaz, S., Riley, D., and Leicht, R. (2013). ”Process Indicators to Track Effectiveness of High-Performance Green Building Projects.” *J. Constr. Eng. Manage.,* 139(12).

Gunhan, S. and Arditi, D. (2005a). “Factors affecting international construction.” *J. Constr. Eng. Manage.*, 131(3), 273-282.

Gunhan, S. and Arditi, D. (2005b). “International expansion decision for construction companies.” *J. Constr. Eng. Manage.,* 131(8), 928-397.

Hallowell, M.R. and Gambatese, J.A. (2010). "Qualitative research: application of the Delphi method to CEM research*." J. Constr. Eng. Manage.*, 136(1): 99-107.

Hasson, F. and Keeney, S. (2011). "Enhancing rigour in the Delphi technique research*." Techn.Forecasting &Social Change*, vol. 78(9), 1695-1704.

Hilbert, M. Miles, I. and Othmer, J. (2009). "Foresight tools for participative policy-making in intergovernmental processes in developing countries: Lessons learned from the Elacc Policy Priorities Delphi." *Tech. Forecasting and Social Change*, 76(7), 880-896.

Horman, M.J.,Riley, D.R., Lapinsky, A.R., Korkmaz, S., Pulaski, M.H., Magent, C.S., Luo, Y., Harding, N. and Dahl, P.K. (2006). "Delivering green buildings: process improvements for sustainable construction." *J. of Green Building* 1(1), 123-140.

Hwang, B.G. and Ng, W.J. (2013)."Project management knowledge and skills for green construction: Overcoming barriers." *Int . J. of Project Manage.*, 31(2), 272-284.

Josephson, P.E. (2003). "Defects and defect costs in construction – a study of seven building projects in Sweden." Department of Management of Construction and Facilities, Chalmers University of Technology, SE-41296, Goteborg, Sweden.

Koskela, L. (1992). Application of the new production philosophy to construction. CIFE Technical Report, No.72, Center for Integrated Facility Engineering, Dept. of Civil Engineering, Stanford University, Stanford, Calif.

Korkmaz, S., Riley, D. and Horman, M. (2010). "Piloting evaluation metrics for sustainable high-performance building project delivery*." J. Constr. Eng. Manage.*, 136(8), 877-885.

Leicht, R.M., Hunter, S.T., Saluja, C. and Messner, J.I. (2010). "Implementing observational research methods to study team performance in construction management." *J. Const. Eng. Manage.*, 136(1), 76-86.

Linstone, H. and Turoff, M. (1975). *The Delphi method: Techniques and applications*. Mass: Addison-Wesley Pub.

Magent, C., Riley, D. and Horman, M. (2005). "High performance building design process model", *ASCE Construction Research Congress*, April 5-7, San Diego, CA, 424-428.

Mitchell, V.W. (1991). "The Delphi technique: An exposition and application." *Tech. Anal. Strat. Manage.*, 3(4), 333-358.

Molenaar,K. R., Sobin, N., and Anrillón, E. (2010). "A synthesis of best-value procurement practices for sustainable design-build projects in the public sector." *J. Green Build.,* 5(4), 148-157.

National Charette Institute (NCI) (2007). "What is a charette?" <http://www.charretteinstitute.org/charrette.html> (accessed Jan. 24, 2014).

Okoli C. and Pawlowski, S.D. (2004). "The Delphi Method as a research tool: an example, design considerations and applications." *Information & Management,* 42(1), 15-29.

Porter, M. and van der Linde, *C.* (1995).*Green and competitive*. Harvard Business Review, 119-134.

Pulaski, M., Pohlman, T., Horman, M. and Riley, D.R. (2003). "Synergies between sustainable design and constructability at the Pentagon."*Proc. ASCE CRC,*1-8.

Riley, D (2009). Personal Conversation Regarding Master's Thesis Conclusion. Pennsylvania State University, Engineering Units. 2 April 2009.

Riley, D., Magent, M. and Horman, M. (2004). "Sustainable metrics: a design process model for high performance buildings." *Proc. CIB World Building Congress* Toronto,CA.

Riley, D. R., Varadan, P. James, J. S., and Thomas, H. R. (2005). "Benefit-cost metrics for design coordination of mechanical, electrical, and plumbing systems in multistory buildings." *J. Constr. Eng. Manage.,* 131(8), 877-889.

Rowe, G. and Wrigt, G. (2001). "Expert opinions in forecasting: The role of the Delphi technique." *Principles of Forecasting, International Series in Operations Research & Management Science*, vol.30, 125-144.

Rowe, G., Wright, G. and Bolger, F. (1991). "Delphi: A reevaluation of research and theory." *Technological Forecasting and Social Change*, 39(3), 235-251.

Simonsson, P., Björnfot, A., Erikshammar, J. and Olofsson, T. (2012). "'Learning to see' the effects of improved workflow in civil engineering projects." *Lean Constr. J.,* 35-48.

Sprau, T. (2009) "Developing the Basis for Process Metrics for Sustainable Building Performance". M.S. Thesis. Department of Architectural Engineering. The Pennsylvania State University.

Swarup, L., Korkmaz, S. and Riley, D. (2011). "Project delivery metrics for susteianble, high performance buildings." *J. Constr. Eng. Manage.,* 137(12), 1043-1051.

Stegall, N. (2004). "Cost implications of LEED Silver Certification for new house residence at Carnegie Mellon University".Senior Honors Research Project, Carnegie Inst. of Tech.

Syal, M.G., Mago, S. and Moody, D. (2007). "Impact of LEED-NC credits on contractors." *J. Archit. Eng.,* 13(4), 174-179.

USGBC (2009). U.S. Green Building Council. "LEED 2009 for New Construction and Major Renovations Rating System." <http://www.usgbc.org/resources/list/study-guides >, (accessed Feb.10,2014).

USGBC (2014). U.S. Green Building Council. <http://www.usgbc.org/discoverleed/ certification/bd-c-new-construction/ > (accessed Feb. 5, 2015).

Vidal, L.A., Marle, F. and Bocquet, J.C. (2011). "Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects." *Expert Systems with Applications,* vol.38, 5388-54.

Weber, M. and Borcherding, K. (1993). "Behavioral influences on weight judgments in multi-attribute decision making." European J. of Op. Research, vol.67, 1-12.

Wu, P. and Low S.P. (2010). "Project Management and Green Buildings: Lessons from the Rating Systems. "*J. of Prof. Issues in Eng. Educ.Pract*.,136(2),64-70.

Yin, R. K. (2003). *Case Study Research,* Sage Publications, 3rd ed., Thousand Oaks

Yue, Z. (2012). "Extension of TOPSIS to determine weight of decision maker for group decision making problems with uncertain information", *Experts Systems with Applications*, 39(7), 6343-6350.

APPENDIX A

Delphi Method Results of Importance Levels for Hierarchically Designed Green Building Project Delivery Attributes

DELPHI METHOD SECOND ROUND RESULTS		Designating Importance Levels to "Project Teams' Qualification in GB Projects" and "Timing of Project Teams' Involvement in GB Processes" by considering LEED® 2009 NC&MR Rating System			
1.	First Level Attributes of GB Project Delivery	Project Team Attributes for Green Building Projects			
		Level of Importance for "Project Teams' Qualification" in GB projects and features considering requirements of LEED® 2009 NC rating systemand related process		Level of Importance for "Timing of Project Teams' Involvement" in GB processes considering requirements of LEED® 2009 NC rating systemand related process	
		Mean.Round-II	SD.Round-II	Mean.Round-II	SD.Round-II
		6,70	1,23	7,00	0,99
	Rating Scale	1 - Without any importance 3 - Moderate importance 5 - Strong importance 7 - Highly important 9 - Extreme importance 2, 4, 6, 8 points refer to the importance level between level represented above.			

2.	Second Level Attributes of GB Project Delivery	Project Teams' Qualification in Green Building Projects and Features			
		Level of Importance for "Project Teams' Education and Knowledge" in GB concepts considering requirements of LEED® 2009 NC rating system and related process		Level of Importance for "Project Teams' Experience" in GB Projects and features considering requirements of LEED® 2009 NC rating systemand related process	
		Mean.Round-II	SD.Round-II	Mean.Round-II	SD.Round-II
	LEED 2009 NC&MR Rating System	6,40	1,26	6,90	0,76

2.	Second Level Attributes of GB Project Delivery	Timing of Involvement for Green Building Projects							
		Level of importance of project teams' involvement in "feasibility" phase to achieve LEED® certification and related process.		Level of importance of project teams' involvement in "schematic design" phase to achieve LEED® certification and related process.		Level of importance of project teams' involvement in "design development" phase to achieve LEED® certification and related process..		Level of importance of project team members's involvement in "construction" phase to achieve LEED® certification and related process.	
		Mean.R-II	SD.R-II	Mean.R-II	SD.R-II	Mean.R-II	SD.R-II	Mean.R-II	SD.R-II
	LEED® 2009 NC&MR Rating System	5,70	0,82	6,00	0,94	7,50	1,18	6,40	0,84
	Rating Scale	1 - Without any importance 3 - Moderate importance 5 - Strong importance 7 - Highly important 9 - Extreme importance 2, 4, 6, 8 points refer to the importance level between level represented above.							

LEED® 2009 for New Construction and Major Renovations	Qualification of Project Teams in GB Projects and Features						
DELPHI METHOD SECOND ROUND RESULTS	Mean Values Regarding the Experience of Project Teams in GB Projects and Features						
	1 - Without any importance 3 - Moderate importance 5 - Strong importance 7 - Highly important 9 - Extreme importance 2, 4, 6, 8 points refer to the importance level between level represented above.						
	Owner	General Contractor	Mechanical Team	Electrical Team	Architectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	6,10	6,70	3,60	3,10	5,10	6,50	3,70
Site Selection	6,70	4,70	2,70	2,30	5,10	3,20	1,90
Development Density and Community Connectivity	6,80	4,80	2,70	2,30	4,90	3,10	2,00
Brownfield Redevelopment	7,10	5,90	3,00	2,60	4,90	4,60	2,30
Alternative Transportation—Public Transportation Access	6,80	4,20	2,70	2,30	5,30	4,10	2,50
Alternative Transportation—Bicycle Storage and Changing Rooms	6,50	4,40	2,70	2,20	5,60	4,00	2,50
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	6,50	4,30	3,10	2,80	5,40	4,20	3,30
Alternative Transportation—Parking Capacity	6,70	4,10	2,80	2,50	5,50	4,00	2,50
Site Development—Protect or Restore Habitat	6,40	5,70	2,90	2,60	5,90	4,70	2,70
Site Development—Maximize Open Space	6,40	5,70	3,10	2,50	5,90	4,30	2,50
Stormwater Design—Quantity Control	6,10	6,40	6,00	2,70	5,40	4,70	3,90
Stormwater Design—Quality Control	6,10	6,40	5,90	2,60	5,40	4,70	3,90
Heat Island Effect—Non-roof	5,90	5,30	3,60	2,80	6,10	4,50	4,60
Heat Island Effect—Roof	6,10	5,30	3,50	3,00	6,20	4,60	4,80
Light Pollution Reduction	6,60	4,90	3,30	5,10	6,10	4,60	5,20
Water Efficiency							
Water Use Reduction—20% Reduction	6,00	5,20	7,00	3,20	5,50	3,50	6,70
Water Efficient Landscaping	5,80	5,20	7,00	3,20	5,70	3,60	6,20
Innovative Wastewater Technologies	5,80	5,20	7,00	3,20	5,40	3,50	6,90
Water Use Reduction	6,00	5,20	6,90	3,20	5,50	3,50	6,40
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	7,00	6,70	7,70	7,20	5,40	5,10	5,10
Minimum Energy Performance	7,00	6,20	7,10	7,20	6,50	4,50	6,40
Fundamental Refrigerant Management	7,20	5,80	7,20	4,80	4,60	4,50	5,60
Optimize Energy Performance	6,90	6,60	7,10	7,40	6,60	4,50	6,50
On-Site Renewable Energy	7,40	6,20	6,30	7,30	5,90	4,60	6,10
Enhanced Commissioning	7,20	6,60	7,40	6,30	4,80	4,90	5,40
Enhanced Refrigerant Management	7,20	5,60	7,10	4,20	4,50	4,50	5,30
Measurement and Verification	6,80	6,40	7,10	7,00	5,00	4,30	4,60
Green Power	7,10	5,40	5,60	6,40	4,60	4,20	5,00
Materials and Resources							
Storage and Collection of Recyclables	6,00	6,20	2,90	2,60	6,70	5,00	2,90
Building Reuse—Maintain Existing Walls, Floors, and Roof	5,90	6,70	3,00	2,60	6,80	5,50	2,60
Building Reuse—Maintain 50% of Interior Non-Structural Elements	5,90	6,70	3,00	2,60	6,80	5,50	2,60
Construction Waste Management	5,80	7,30	4,40	4,30	6,20	6,80	3,40
Materials Reuse	6,00	6,70	3,00	2,50	6,60	5,90	4,90
Recycled Content	6,10	6,30	3,00	2,50	6,60	5,90	6,30
Regional Materials	5,90	6,30	3,60	3,10	6,60	6,10	7,00
Rapidly Renewable Materials	6,20	6,20	2,90	2,50	6,70	5,90	6,40
Certified Wood	6,20	6,30	2,90	2,50	6,70	5,50	7,00
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	6,20	5,10	7,10	3,80	6,00	3,60	3,40
Environmental Tobacco Smoke (ETS) Control	6,50	4,50	5,30	3,50	5,50	3,90	2,80
Outdoor Air Delivery Monitoring	6,00	5,20	6,70	3,80	4,60	3,70	2,90
Increased Ventilation	6,00	4,80	6,90	3,60	4,90	3,60	2,90
Construction IAQ Management Plan—During Construction	5,90	5,70	7,40	4,00	5,00	4,70	3,10
Construction IAQ Management Plan—Before Occupancy	5,90	5,50	7,40	3,60	5,00	4,10	3,00
Low-Emitting Materials—Adhesives and Sealants	6,20	6,70	4,90	4,00	6,20	5,30	6,30
Low-Emitting Materials—Paints and Coatings	6,20	6,70	4,50	4,00	6,20	5,30	6,20
Low-Emitting Materials—Flooring Systems	6,20	6,50	3,90	3,50	6,40	5,30	6,20
Low-Emitting Materials—Composite Wood and Agrifiber Products	6,20	6,50	3,90	3,50	6,40	5,30	6,20
Indoor Chemical and Pollutant Source Control	6,40	6,20	5,20	3,50	6,00	5,30	5,30
Controllability of Systems—Lighting	6,10	5,80	3,80	6,40	5,60	3,90	4,20
Controllability of Systems—Thermal Comfort	6,10	5,70	6,70	4,20	4,90	3,80	3,60
Thermal Comfort—Design	6,10	5,30	7,00	4,10	4,70	3,90	2,90
Thermal Comfort—Verification	6,10	5,20	5,50	4,10	4,10	3,50	2,90
Daylight and Views—Daylight	6,00	4,20	3,50	4,10	6,60	3,50	3,00
Daylight and Views—Views	6,10	3,90	2,80	3,60	6,90	3,50	2,90

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Construction and Major Renovations	Qualification of Project Teams in GB Projects and Features						
DELPHI METHOD SECOND ROUND RESULTS	Standard Deviation Regarding the Experience of Project Teams in GB Projects and Features						
	Owner	General Contractor	Mechanical Team	Electrical Team	Archiectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	1,52	1,64	1,26	1,45	1,52	1,84	1,95
Site Selection	1,70	2,00	0,95	0,82	2,18	1,14	0,74
Development Density and Community Connectivity	1,81	2,25	0,95	0,82	2,69	1,29	0,82
Brownfield Redevelopment	1,60	1,60	1,15	1,17	2,69	2,17	1,06
Alternative Transportation—Public Transportation Access	1,81	2,15	0,95	0,82	2,45	1,37	1,08
Alternative Transportation—Bicycle Storage and Changing Rooms	1,72	1,90	0,95	0,79	1,96	1,33	1,08
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	1,43	1,89	1,20	1,14	1,65	1,32	1,25
Alternative Transportation—Parking Capacity	1,95	2,13	1,03	0,85	2,12	1,33	1,08
Site Development—Protect or Restore Habitat	1,78	2,16	1,20	1,07	2,13	2,00	1,34
Site Development—Maximize Open Space	1,90	1,77	1,45	0,85	2,13	1,89	1,08
Stormwater Design—Quantity Control	1,45	1,65	1,76	1,16	2,01	1,95	1,60
Stormwater Design—Quality Control	1,45	1,65	1,79	1,17	2,01	1,95	1,60
Heat Island Effect—Non-roof	1,45	1,70	1,58	1,14	1,91	1,72	1,43
Heat Island Effect—Roof	1,45	1,70	1,51	1,15	1,99	1,71	1,75
Light Pollution Reduction	1,58	1,73	1,34	1,79	1,85	1,71	1,99
Water Efficiency							
Water Use Reduction—20% Reduction	1,76	1,48	1,70	1,48	1,51	1,65	1,42
Water Efficient Landscaping	1,48	1,48	1,70	1,48	1,83	1,65	0,92
Innovative Wastewater Technologies	1,48	1,48	1,70	1,48	1,51	1,65	1,45
Water Use Reduction	1,76	1,48	1,60	1,48	1,51	1,65	1,35
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	1,25	1,16	0,82	1,03	1,58	0,99	0,99
Minimum Energy Performance	1,25	1,40	1,29	1,48	2,01	1,43	1,35
Fundamental Refrigerant Management	1,48	1,69	1,93	2,20	1,71	1,43	0,70
Optimize Energy Performance	1,10	1,58	1,37	1,58	2,01	1,43	1,51
On-Site Renewable Energy	1,58	1,32	1,77	1,64	2,02	1,51	1,29
Enhanced Commissioning	1,48	1,17	1,07	1,83	2,15	1,45	0,97
Enhanced Refrigerant Management	1,48	1,58	1,85	1,55	1,84	1,65	1,06
Measurement and Verification	1,40	1,26	1,20	1,25	1,70	1,70	2,27
Green Power	1,91	1,84	2,55	2,07	2,41	1,69	2,26
Materials and Resources							
Storage and Collection of Recyclables	1,63	1,99	1,10	0,84	1,16	2,05	1,52
Building Reuse—Maintain Existing Walls, Floors, and Roof	1,37	1,64	1,15	0,84	1,62	1,96	1,07
Building Reuse—Maintain 50% of Interior Non-Structural Elements	1,37	1,64	1,15	0,84	1,62	1,96	1,07
Construction Waste Management	1,75	1,49	1,58	1,70	1,32	1,75	1,43
Materials Reuse	1,41	1,64	1,15	0,85	1,58	1,52	2,33
Recycled Content	1,20	1,49	1,15	0,85	1,58	1,52	1,83
Regional Materials	1,20	1,49	2,22	2,23	1,58	1,79	1,63
Rapidly Renewable Materials	1,14	1,48	1,10	0,85	1,49	1,52	1,90
Certified Wood	1,14	1,49	1,10	0,85	1,49	1,72	1,63
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	1,55	1,66	1,66	1,81	2,31	1,65	1,71
Environmental Tobacco Smoke (ETS) Control	1,96	1,84	2,06	1,51	1,43	1,73	1,23
Outdoor Air Delivery Monitoring	1,83	1,62	1,64	1,40	1,51	1,64	1,20
Increased Ventilation	1,83	1,48	1,73	1,58	2,13	1,65	1,20
Construction IAQ Management Plan—During Construction	1,37	1,25	1,71	1,41	2,54	1,42	1,79
Construction IAQ Management Plan—Before Occupancy	1,37	1,27	1,43	1,51	2,54	1,52	1,89
Low-Emitting Materials—Adhesives and Sealants	1,03	1,57	1,60	1,41	1,40	1,49	1,77
Low-Emitting Materials—Paints and Coatings	1,03	1,57	1,58	1,41	1,40	1,49	1,87
Low-Emitting Materials—Flooring Systems	1,03	1,35	1,97	1,65	1,51	1,49	1,87
Low-Emitting Materials—Composite Wood and Agrifiber Products	1,03	1,35	1,97	1,65	1,51	1,49	1,87
Indoor Chemical and Pollutant Source Control	1,17	1,40	1,55	1,65	1,83	1,49	1,64
Controllability of Systems—Lighting	1,66	1,23	1,69	1,90	2,22	1,66	1,55
Controllability of Systems—Thermal Comfort	1,66	1,16	1,83	1,69	1,97	1,48	1,17
Thermal Comfort—Design	1,66	1,95	1,63	1,79	2,26	1,66	1,20
Thermal Comfort—Verification	1,66	1,87	2,37	1,79	2,51	1,58	1,20
Daylight and Views—Daylight	1,63	2,15	2,01	1,20	1,51	1,78	1,15
Daylight and Views—Views	1,66	2,18	1,40	1,84	1,60	1,78	1,20

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Conctruction and Major Renovations	Qualification of Project Teams in GB Projects and Features						
DELPHI METHOD SECOND ROUND RESULTS	Mean Values Regarding the Education and Knowledge of Project Teams in GB Projects and Features 1 - Without any importance 3 - Moderate importance 5 - Strong importance 7 - Highly important 9 - Extreme importance 2, 4, 6, 8 points refer to the importance level between level represented above.						
	Owner	General Contractor	Mechanical Team	Electrical Team	Architectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	7,10	8,20	4,30	4,10	5,70	7,10	3,10
Site Selection	7,30	4,30	2,00	2,00	4,80	2,20	1,90
Development Density and Community Connectivity	7,30	4,60	2,00	2,00	4,50	2,20	1,90
Brownfield Redevelopment	7,30	6,70	3,00	2,20	4,40	4,60	1,90
Alternative Transportation—Public Transportation Access	7,30	4,30	2,40	2,00	5,70	2,30	1,90
Alternative Transportation—Bicycle Storage and Changing Rooms	7,30	4,90	2,60	2,00	6,50	3,70	2,10
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	7,10	4,90	2,70	4,40	6,10	3,90	2,90
Alternative Transportation—Parking Capacity	7,30	4,60	2,20	2,00	6,20	2,40	1,90
Site Development—Protect or Restore Habitat	7,10	6,00	2,40	2,20	6,60	5,20	1,90
Site Development—Maximize Open Space	7,50	5,30	2,20	2,00	6,50	4,60	1,90
Stormwater Design—Quantity Control	6,50	6,30	6,40	2,30	6,10	5,10	2,80
Stormwater Design—Quality Control	6,50	6,30	6,40	2,30	6,10	5,10	2,90
Heat Island Effect—Non-roof	6,40	6,00	3,50	2,40	7,70	3,60	3,40
Heat Island Effect—Roof	6,40	6,00	3,50	2,50	7,50	4,80	3,00
Light Pollution Reduction	6,60	5,70	3,50	6,60	7,40	4,60	3,50
Water Efficiency							
Water Use Reduction—20% Reduction	6,70	5,10	6,60	2,50	5,70	3,90	6,00
Water Efficient Landscaping	6,50	5,00	5,40	2,50	5,90	3,90	5,60
Innovative Wastewater Technologies	6,50	5,00	6,70	2,50	5,60	3,90	5,80
Water Use Reduction	6,70	5,00	6,60	2,50	5,70	3,90	5,80
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	7,00	6,30	7,70	7,40	4,90	4,70	4,90
Minimum Energy Performance	7,10	5,80	7,70	7,40	6,10	4,40	6,30
Fundamental Refrigerant Management	7,20	5,60	7,70	3,80	4,50	3,50	5,70
Optimize Energy Performance	7,10	6,00	7,70	7,50	6,00	4,10	6,30
On-Site Renewable Energy	7,30	5,40	7,50	7,50	5,30	4,30	5,70
Enhanced Commissioning	7,10	6,40	7,70	7,50	4,90	4,50	5,30
Enhanced Refrigerant Management	7,00	5,40	7,70	4,40	4,40	3,50	5,70
Measurement and Verification	6,90	5,80	7,50	7,10	5,10	4,00	5,30
Green Power	7,70	4,90	6,50	6,20	4,80	3,30	5,00
Materials and Resources							
Storage and Collection of Recyclables	7,10	5,70	3,30	2,90	5,90	5,20	3,50
Building Reuse—Maintain Existing Walls, Floors, and Roof	6,90	6,80	3,40	3,00	6,90	5,40	3,40
Building Reuse—Maintain 50% of Interior Non-Structural Elements	6,90	6,80	3,40	3,00	6,90	5,40	3,40
Construction Waste Management	6,70	7,30	4,50	4,20	5,80	7,00	4,10
Materials Reuse	7,10	7,00	3,50	3,00	6,60	5,60	5,10
Recycled Content	7,10	7,10	3,50	3,00	6,60	5,90	6,00
Regional Materials	6,90	7,10	4,10	3,60	6,80	6,00	6,70
Rapidly Renewable Materials	7,10	6,70	3,30	2,90	6,70	5,80	5,90
Certified Wood	7,10	6,70	3,30	2,90	6,70	5,40	6,50
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	5,80	5,80	7,80	3,30	6,80	3,80	5,40
Environmental Tobacco Smoke (ETS) Control	6,70	5,60	5,70	3,00	6,80	4,40	3,70
Outdoor Air Delivery Monitoring	6,10	5,60	7,80	4,00	5,80	4,30	5,30
Increased Ventilation	5,80	5,60	7,40	3,60	6,50	4,20	5,00
Construction IAQ Management Plan—During Construction	6,10	6,30	6,30	4,00	6,20	5,80	4,30
Construction IAQ Management Plan—Before Occupancy	6,10	6,30	7,30	3,50	6,10	5,10	4,30
Low-Emitting Materials—Adhesives and Sealants	6,30	6,40	4,80	3,10	7,50	6,00	6,50
Low-Emitting Materials—Paints and Coatings	6,30	6,40	4,80	3,10	7,50	6,00	6,50
Low-Emitting Materials—Flooring Systems	6,30	6,40	4,10	2,70	7,50	6,00	6,50
Low-Emitting Materials—Composite Wood and Agrifiber Products	6,30	6,40	4,10	2,70	7,50	6,00	6,50
Indoor Chemical and Pollutant Source Control	6,30	5,90	6,20	3,00	7,50	5,40	4,50
Controllability of Systems—Lighting	5,90	5,50	4,20	6,80	7,50	5,60	4,70
Controllability of Systems—Thermal Comfort	5,90	5,50	7,00	3,40	6,70	4,70	4,30
Thermal Comfort—Design	5,90	5,20	7,20	3,60	6,20	3,80	4,20
Thermal Comfort—Verification	6,30	5,10	6,40	4,00	6,00	3,80	3,90
Daylight and Views—Daylight	5,90	4,70	4,30	4,10	7,60	3,80	4,00
Daylight and Views—Views	5,90	4,60	4,30	3,70	7,60	3,80	4,00

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Conctruction and Major Renovations	Qualification of Project Teams in GB Projects and Features						
DELPHI METHOD SECOND ROUND RESULTS	Standard Deviation Regarding the Education and Knowledge of Project Teams in GB Projects and Features						
	Owner	General Contractor	Mechanical Team	Electrical Team	Archiectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	1,45	1,23	1,25	1,10	1,25	1,60	2,33
Site Selection	1,57	2,06	0,94	0,82	2,20	1,23	0,74
Development Density and Community Connectivity	1,57	1,90	0,94	0,82	2,51	1,23	0,74
Brownfield Redevelopment	1,57	1,83	1,41	1,23	2,50	2,32	0,74
Alternative Transportation—Public Transportation Access	1,57	2,16	1,07	0,82	1,83	1,25	0,74
Alternative Transportation—Bicycle Storage and Changing Rooms	1,57	1,85	0,97	0,82	1,51	1,70	0,74
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	1,45	1,85	1,25	1,26	1,29	1,73	1,20
Alternative Transportation—Parking Capacity	1,57	2,22	0,92	0,82	1,69	1,26	0,74
Site Development—Protect or Restore Habitat	1,45	2,16	1,26	1,23	1,58	2,10	0,74
Site Development—Maximize Open Space	1,51	1,83	0,92	0,82	1,51	2,07	0,74
Stormwater Design—Quantity Control	1,51	1,64	2,27	1,16	1,29	1,73	1,32
Stormwater Design—Quality Control	1,51	1,64	2,27	1,16	1,45	1,73	1,29
Heat Island Effect—Non-roof	1,43	1,49	1,96	1,26	1,42	1,65	1,35
Heat Island Effect—Roof	1,43	1,49	1,96	1,27	1,35	1,87	1,41
Light Pollution Reduction	1,65	1,42	1,96	2,37	1,43	1,71	2,01
Water Efficiency							
Water Use Reduction—20% Reduction	1,77	1,10	1,58	1,18	1,64	1,37	1,94
Water Efficient Landscaping	1,58	1,15	2,27	1,18	1,91	1,37	1,65
Innovative Wastewater Technologies	1,58	1,15	1,49	1,18	1,65	1,37	1,93
Water Use Reduction	1,77	1,15	1,58	1,18	1,64	1,37	1,93
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	1,25	1,70	1,42	1,35	2,02	1,95	1,91
Minimum Energy Performance	1,29	1,32	1,42	1,35	1,52	1,65	1,77
Fundamental Refrigerant Management	1,40	1,26	1,42	1,69	2,01	1,51	1,49
Optimize Energy Performance	1,29	1,63	1,42	1,43	1,56	1,60	1,77
On-Site Renewable Energy	1,42	1,17	1,65	1,43	1,83	1,83	1,49
Enhanced Commissioning	1,29	1,78	1,42	1,43	2,02	2,01	1,64
Enhanced Refrigerant Management	1,25	1,17	1,42	2,22	2,01	1,51	1,49
Measurement and Verification	1,45	1,62	1,78	1,52	2,23	1,41	1,64
Green Power	1,25	1,60	2,37	1,99	2,66	1,70	2,54
Materials and Resources							
Storage and Collection of Recyclables	0,99	1,70	1,70	1,29	1,45	1,62	1,90
Building Reuse—Maintain Existing Walls, Floors, and Roof	1,20	1,40	1,84	1,49	1,73	2,07	2,07
Building Reuse—Maintain 50% of Interior Non-Structural Elements	1,20	1,40	1,84	1,49	1,73	2,07	2,07
Construction Waste Management	1,64	1,42	2,27	2,20	2,25	1,76	1,97
Materials Reuse	0,99	1,56	1,78	1,49	2,17	1,90	2,18
Recycled Content	0,99	1,45	1,78	1,49	1,78	1,60	2,11
Regional Materials	1,20	1,45	2,47	2,41	1,69	1,89	2,06
Rapidly Renewable Materials	0,99	1,70	1,70	1,29	1,77	1,62	2,13
Certified Wood	0,99	1,70	1,70	1,29	1,77	1,78	2,07
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	1,32	1,03	1,23	1,49	2,30	2,15	0,70
Environmental Tobacco Smoke (ETS) Control	1,57	1,51	2,31	1,33	1,62	1,65	1,49
Outdoor Air Delivery Monitoring	1,73	0,97	1,23	1,41	2,04	1,70	0,95
Increased Ventilation	1,62	0,97	1,43	1,84	2,32	1,93	0,82
Construction IAQ Management Plan—During Construction	1,29	0,82	2,54	1,76	2,35	1,69	1,95
Construction IAQ Management Plan—Before Occupancy	1,29	0,82	1,42	1,72	2,38	1,45	1,95
Low-Emitting Materials—Adhesives and Sealants	1,25	1,65	2,20	1,66	1,08	1,56	1,78
Low-Emitting Materials—Paints and Coatings	1,25	1,65	2,20	1,66	1,08	1,56	1,78
Low-Emitting Materials—Flooring Systems	1,25	1,65	2,18	1,34	1,08	1,56	1,78
Low-Emitting Materials—Composite Wood and Agrifiber Products	1,25	1,65	2,18	1,34	1,08	1,56	1,78
Indoor Chemical and Pollutant Source Control	1,25	1,45	1,48	1,49	1,08	1,43	1,65
Controllability of Systems—Lighting	1,60	1,18	1,99	1,87	1,08	1,78	1,25
Controllability of Systems—Thermal Comfort	1,60	1,18	1,49	1,71	1,49	1,49	1,70
Thermal Comfort—Design	1,60	1,62	1,62	1,78	2,35	1,93	1,62
Thermal Comfort—Verification	1,83	1,97	1,51	2,36	2,45	1,93	1,73
Daylight and Views—Daylight	1,60	1,95	1,89	2,23	1,17	1,93	1,83
Daylight and Views—Views	1,60	1,84	1,89	2,06	1,17	1,93	1,83

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Construction and Major Renovations	Timing of Project Teams' Involvement in GB Processes						
DELPHI METHOD SECOND ROUND RESULTS	Mean Values Regarding the Timing of Project Teams' Involvement in Feasibility (including feasibility, project initiation)						
	1 - Without any importance 3 - Moderate importance 5 - Strong importance 7 - Highly important 9 - Extreme importance 2, 4, 6, 8 points refer to the importance level between level represented above.						
	Owner	General Contractor	Mechanical Team	Electrical Team	Architectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	7,10	6,40	3,90	3,40	4,90	4,40	2,20
Site Selection	7,90	4,60	3,30	3,00	4,90	2,60	2,20
Development Density and Community Connectivity	7,70	4,60	3,30	3,00	4,70	2,90	2,30
Brownfield Redevelopment	7,80	5,00	3,30	3,00	4,90	2,80	2,50
Alternative Transportation—Public Transportation Access	7,40	4,30	3,10	3,00	4,90	2,80	2,10
Alternative Transportation—Bicycle Storage and Changing Rooms	7,10	4,80	3,60	3,00	5,90	3,00	2,50
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	7,50	4,80	3,30	3,60	5,80	3,20	2,70
Alternative Transportation—Parking Capacity	7,40	4,50	3,10	3,10	5,60	2,80	2,10
Site Development—Protect or Restore Habitat	7,40	4,80	3,60	3,00	6,00	3,00	2,30
Site Development—Maximize Open Space	7,40	4,80	3,60	3,00	6,00	3,10	2,30
Stormwater Design—Quantity Control	7,50	5,10	5,00	3,00	5,50	3,50	3,00
Stormwater Design—Quality Control	7,50	4,70	5,00	3,00	5,50	3,20	3,00
Heat Island Effect—Non-roof	7,20	4,80	3,90	3,10	5,90	3,30	3,20
Heat Island Effect—Roof	7,20	4,80	3,90	3,10	5,80	3,10	3,20
Light Pollution Reduction	7,20	4,50	3,30	5,00	6,00	3,20	3,80
Water Efficiency							
Water Use Reduction—20% Reduction	7,50	4,50	6,30	3,00	6,00	3,55	3,80
Water Efficient Landscaping	7,50	4,50	6,20	3,00	6,20	3,55	3,80
Innovative Wastewater Technologies	7,70	4,50	6,10	3,00	6,10	3,55	3,80
Water Use Reduction	7,50	4,50	6,20	3,00	6,00	3,55	3,80
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	7,70	5,30	6,40	5,90	5,30	3,50	3,60
Minimum Energy Performance	7,70	5,70	6,50	6,30	6,00	3,20	3,80
Fundamental Refrigerant Management	7,70	5,50	6,50	4,10	5,30	3,00	4,00
Optimize Energy Performance	7,70	5,50	6,50	6,30	6,20	3,00	3,80
On-Site Renewable Energy	7,80	5,40	5,80	6,40	5,70	3,00	4,00
Enhanced Commissioning	7,80	5,40	6,50	5,10	5,50	3,20	3,60
Enhanced Refrigerant Management	7,80	5,40	6,30	3,90	5,50	3,00	4,00
Measurement and Verification	7,70	5,40	5,90	5,90	5,50	3,00	3,60
Green Power	7,80	5,00	5,50	5,40	5,30	3,00	4,00
Materials and Resources							
Storage and Collection of Recyclables	7,20	5,20	3,60	3,20	6,70	2,70	2,80
Building Reuse—Maintain Existing Walls, Floors, and Roof	7,80	5,70	4,50	3,90	7,50	3,40	2,80
Building Reuse—Maintain 50% of Interior Non-Structural Elements	7,60	5,70	4,50	3,90	7,50	3,40	2,80
Construction Waste Management	7,10	6,20	5,10	4,20	6,60	3,90	3,60
Materials Reuse	7,40	5,30	3,90	3,30	6,90	2,80	3,40
Recycled Content	7,50	5,30	4,00	3,30	6,90	2,90	3,60
Regional Materials	7,50	5,30	3,90	3,30	6,90	2,90	3,60
Rapidly Renewable Materials	7,50	5,30	3,90	3,30	6,90	2,90	3,60
Certified Wood	7,50	5,30	3,90	3,30	6,90	2,90	3,60
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	7,00	5,30	5,80	3,30	5,30	2,70	3,80
Environmental Tobacco Smoke (ETS) Control	7,10	5,30	4,90	3,30	5,90	2,70	3,60
Outdoor Air Delivery Monitoring	7,20	5,30	5,70	3,50	5,60	2,70	3,60
Increased Ventilation	7,00	5,30	6,00	3,30	5,40	2,50	3,60
Construction IAQ Management Plan—During Construction	6,50	5,50	5,20	3,70	5,50	2,70	3,70
Construction IAQ Management Plan—Before Occupancy	7,40	5,40	5,30	3,50	5,20	2,90	3,70
Low-Emitting Materials—Adhesives and Sealants	7,30	5,80	4,50	3,40	6,20	3,30	4,60
Low-Emitting Materials—Paints and Coatings	7,30	5,80	4,20	3,40	6,30	3,30	4,60
Low-Emitting Materials—Flooring Systems	7,30	5,80	3,80	3,30	6,20	3,30	4,60
Low-Emitting Materials—Composite Wood and Agrifiber Products	7,30	5,80	3,80	3,30	6,30	3,30	4,60
Indoor Chemical and Pollutant Source Control	7,30	5,30	4,70	3,80	5,90	2,90	4,30
Controllability of Systems—Lighting	7,30	5,30	3,70	5,40	6,30	2,90	4,10
Controllability of Systems—Thermal Comfort	7,30	5,30	5,50	3,90	6,30	2,70	3,70
Thermal Comfort—Design	7,10	5,00	5,60	4,20	5,90	2,70	3,70
Thermal Comfort—Verification	7,30	4,60	5,40	3,80	5,90	2,70	3,70
Daylight and Views—Daylight	7,10	5,00	4,40	3,70	6,30	2,90	3,90
Daylight and Views—Views	7,10	4,80	4,20	3,80	6,30	2,90	3,70

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Construction and Major Renovations	Timing of Project Teams' Involvement in GB Processes						
DELPHI METHOD SECOND ROUND RESULTS	Standard Deviation Regarding the Timing of Project Teams' Involvement in Feasibility (including feasibility, project initiation)						
	Owner	General Contractor	Mechanical Team	Electrical Team	Archiectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	1,45	1,51	0,74	0,84	1,97	2,12	0,92
Site Selection	0,88	1,07	0,82	0,94	1,97	1,51	0,92
Development Density and Community Connectivity	1,06	1,07	0,82	0,94	1,95	1,66	1,16
Brownfield Redevelopment	0,92	1,76	0,82	0,94	1,97	1,55	1,43
Alternative Transportation—Public Transportation Access	1,07	1,34	0,88	0,94	2,08	1,55	0,74
Alternative Transportation—Bicycle Storage and Changing Rooms	1,45	1,14	1,07	0,94	1,37	1,41	0,85
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	0,97	1,14	0,82	1,07	1,62	1,55	1,64
Alternative Transportation—Parking Capacity	1,17	1,43	0,88	0,88	1,58	1,55	0,74
Site Development—Protect or Restore Habitat	1,07	1,14	1,17	0,94	1,49	1,41	0,95
Site Development—Maximize Open Space	1,07	1,14	1,17	0,94	1,49	1,37	0,95
Stormwater Design—Quantity Control	0,97	0,99	2,05	0,94	1,27	1,35	1,63
Stormwater Design—Quality Control	0,97	0,95	2,05	0,94	1,27	1,03	1,63
Heat Island Effect—Non-roof	1,23	1,40	1,10	0,88	1,52	1,57	1,87
Heat Island Effect—Roof	1,23	1,40	1,10	0,88	1,48	1,10	1,62
Light Pollution Reduction	1,23	1,43	1,06	2,16	1,49	1,23	2,15
Water Efficiency							
Water Use Reduction—20% Reduction	0,85	1,35	1,70	1,15	1,49	1,30	1,32
Water Efficient Landscaping	0,85	1,35	1,99	1,15	1,32	1,30	1,32
Innovative Wastewater Technologies	0,95	1,35	1,91	1,15	1,52	1,30	1,32
Water Use Reduction	0,85	1,35	1,99	1,15	1,49	1,30	1,32
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	0,82	0,48	1,07	1,45	1,70	1,08	1,78
Minimum Energy Performance	0,82	0,82	0,97	1,49	1,15	1,32	1,55
Fundamental Refrigerant Management	0,82	0,85	0,97	1,91	1,95	1,25	1,49
Optimize Energy Performance	0,82	0,85	1,27	1,64	1,32	1,25	1,55
On-Site Renewable Energy	0,92	0,70	1,40	1,78	1,95	1,25	1,49
Enhanced Commissioning	0,92	0,70	1,27	1,79	1,90	1,03	1,78
Enhanced Refrigerant Management	0,92	0,70	1,16	1,91	1,90	1,25	1,49
Measurement and Verification	0,82	0,70	1,52	1,45	1,90	1,25	1,78
Green Power	0,92	1,15	1,43	1,96	1,77	1,25	1,49
Materials and Resources							
Storage and Collection of Recyclables	1,48	2,04	1,71	1,69	1,16	1,25	0,92
Building Reuse—Maintain Existing Walls, Floors, and Roof	1,14	1,25	1,18	1,52	1,18	1,35	0,92
Building Reuse—Maintain 50% of Interior Non-Structural Elements	1,07	1,25	1,18	1,52	1,18	1,35	0,92
Construction Waste Management	1,45	1,48	1,97	1,87	1,71	1,91	2,01
Materials Reuse	0,97	1,95	1,60	1,64	0,99	1,23	1,43
Recycled Content	0,97	1,95	1,70	1,64	0,99	1,20	1,43
Regional Materials	0,97	1,95	1,60	1,64	0,99	1,20	1,43
Rapidly Renewable Materials	0,97	1,95	1,60	1,64	0,99	1,20	1,43
Certified Wood	0,97	1,95	1,60	1,64	0,99	1,20	1,43
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	1,56	1,25	1,69	1,25	1,95	1,25	1,14
Environmental Tobacco Smoke (ETS) Control	1,60	1,25	1,66	1,25	1,66	1,25	1,35
Outdoor Air Delivery Monitoring	1,40	1,25	1,57	0,97	1,90	1,25	1,35
Increased Ventilation	1,56	1,25	1,70	1,25	1,84	1,27	1,35
Construction IAQ Management Plan—During Construction	1,84	1,18	1,69	0,95	2,01	1,25	1,42
Construction IAQ Management Plan—Before Occupancy	1,51	1,35	1,25	1,27	2,30	1,45	1,42
Low-Emitting Materials—Adhesives and Sealants	1,25	1,14	1,08	1,17	1,32	1,42	1,07
Low-Emitting Materials—Paints and Coatings	1,25	1,14	1,03	1,17	1,34	1,42	1,07
Low-Emitting Materials—Flooring Systems	1,25	1,14	1,40	1,25	1,32	1,42	1,07
Low-Emitting Materials—Composite Wood and Agrifiber Products	1,25	1,14	1,40	1,25	1,34	1,42	1,07
Indoor Chemical and Pollutant Source Control	1,25	1,25	1,06	1,81	1,60	1,45	0,95
Controllability of Systems—Lighting	1,25	1,25	1,49	1,65	1,25	1,45	1,10
Controllability of Systems—Thermal Comfort	1,25	1,25	1,51	1,45	1,25	1,49	1,42
Thermal Comfort—Design	1,29	1,56	1,71	1,93	1,73	1,49	1,42
Thermal Comfort—Verification	1,42	2,01	1,90	1,40	1,73	1,49	1,42
Daylight and Views—Daylight	1,29	1,56	1,43	1,25	1,34	1,45	1,20
Daylight and Views—Views	1,29	1,69	1,75	1,40	1,34	1,45	1,42

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Conctruction and Major Renovations	Timing of Project Teams' Involvement in GB Processes						
DELPHI METHOD SECOND ROUND RESULTS	Mean Values of Timing of Project Teams' Involvement in Schematic Design (project planning,preliminary design, material selection) 1 - Without any importance 3 - Moderate importance 5 - Strong importance 7 - Highly important 9 - Extreme importance 2, 4, 6, 8 points refer to the importance level between level represented above.						
	Owner	General Contractor	Mechanical Team	Electrical Team	Archiectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	7,10	5,30	3,20	2,80	6,40	3,30	2,40
Site Selection	7,10	4,10	3,60	3,50	7,00	2,50	2,20
Development Density and Community Connectivity	7,30	4,10	2,90	2,90	7,10	2,20	2,20
Brownfield Redevelopment	7,10	4,20	3,10	2,90	6,50	2,60	2,20
Alternative Transportation—Public Transportation Access	7,10	4,10	3,00	2,90	7,00	2,20	1,80
Alternative Transportation—Bicycle Storage and Changing Rooms	6,90	3,90	2,90	2,80	7,40	2,20	1,80
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	7,60	4,40	3,00	4,20	7,30	2,60	2,20
Alternative Transportation—Parking Capacity	7,50	4,10	2,90	3,00	7,40	2,60	1,80
Site Development—Protect or Restore Habitat	7,70	4,30	2,90	3,00	7,10	2,40	1,90
Site Development—Maximize Open Space	7,70	4,50	2,80	2,60	7,30	2,40	2,40
Stormwater Design—Quantity Control	7,40	4,70	4,90	2,60	7,00	2,50	2,70
Stormwater Design—Quality Control	7,40	4,70	5,70	2,50	7,20	2,50	2,90
Heat Island Effect—Non-roof	7,40	4,50	4,30	2,60	7,30	2,50	3,20
Heat Island Effect—Roof	7,50	4,50	3,60	2,60	7,40	2,50	3,30
Light Pollution Reduction	7,30	4,50	3,40	5,60	7,20	2,50	3,40
Water Efficiency							
Water Use Reduction—20% Reduction	7,60	5,00	7,40	3,60	7,60	3,50	4,50
Water Efficient Landscaping	7,70	5,00	7,40	3,40	7,60	3,60	4,50
Innovative Wastewater Technologies	7,70	5,00	7,30	3,50	7,60	3,50	4,50
Water Use Reduction	7,70	5,00	7,40	3,40	7,60	3,50	4,50
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	8,10	5,70	7,20	6,80	6,20	4,00	5,10
Minimum Energy Performance	8,10	5,30	7,30	7,50	7,40	3,50	5,20
Fundamental Refrigerant Management	8,20	5,50	7,40	4,80	4,50	3,20	5,60
Optimize Energy Performance	8,00	5,40	7,50	7,30	7,50	3,90	5,70
On-Site Renewable Energy	8,20	5,10	6,80	7,40	6,90	4,90	5,40
Enhanced Commissioning	8,20	5,20	7,20	5,60	5,90	5,40	5,40
Enhanced Refrigerant Management	8,20	5,40	7,40	4,50	5,40	3,40	5,20
Measurement and Verification	7,70	5,00	6,90	6,70	5,30	4,20	4,90
Green Power	8,00	4,50	5,80	6,30	3,90	3,00	4,80
Materials and Resources							
Storage and Collection of Recyclables	7,60	5,10	3,30	2,70	7,90	3,20	2,90
Building Reuse—Maintain Existing Walls, Floors, and Roof	8,10	5,20	3,60	2,80	8,00	3,70	2,70
Building Reuse—Maintain 50% of Interior Non-Structural Elements	8,00	5,20	3,50	3,00	8,10	3,60	2,70
Construction Waste Management	7,50	7,20	4,00	3,60	6,60	4,50	3,10
Materials Reuse	7,60	6,10	3,40	2,90	7,50	3,90	4,90
Recycled Content	7,40	6,10	3,50	3,00	7,80	3,90	5,90
Regional Materials	7,70	6,10	3,60	3,00	7,60	3,90	5,90
Rapidly Renewable Materials	7,40	6,10	3,50	3,00	7,60	3,90	5,90
Certified Wood	7,60	6,30	3,40	2,90	7,60	3,90	5,90
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	6,90	4,60	7,70	4,50	6,60	3,10	4,90
Environmental Tobacco Smoke (ETS) Control	7,30	4,80	6,60	4,20	7,00	3,80	3,80
Outdoor Air Delivery Monitoring	7,10	5,00	7,60	4,30	6,40	3,50	4,40
Increased Ventilation	6,90	4,80	7,80	4,10	6,40	3,40	4,60
Construction IAQ Management Plan—During Construction	6,70	5,70	6,90	4,20	5,90	4,30	3,70
Construction IAQ Management Plan—Before Occupancy	6,70	6,00	7,10	4,10	5,70	4,10	3,60
Low-Emitting Materials—Adhesives and Sealants	6,80	5,60	6,00	4,50	7,40	4,50	5,10
Low-Emitting Materials—Paints and Coatings	6,80	5,60	5,00	4,50	7,40	4,40	5,10
Low-Emitting Materials—Flooring Systems	6,80	5,60	4,20	3,70	7,30	4,40	5,10
Low-Emitting Materials—Composite Wood and Agrifiber Products	6,80	5,60	4,10	3,60	7,30	4,40	5,10
Indoor Chemical and Pollutant Source Control	7,00	5,40	6,80	4,10	7,30	4,20	3,50
Controllability of Systems—Lighting	7,10	5,30	4,30	6,70	7,10	3,50	3,10
Controllability of Systems—Thermal Comfort	7,10	5,20	7,50	4,80	7,00	3,40	3,50
Thermal Comfort—Design	7,10	5,00	7,50	4,30	6,50	3,40	3,70
Thermal Comfort—Verification	7,30	4,40	7,20	4,00	6,30	3,40	3,40
Daylight and Views—Daylight	7,40	4,20	4,20	5,10	7,20	3,70	2,90
Daylight and Views—Views	7,40	4,00	4,70	4,50	7,30	3,30	2,70

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Conctruction and Major Renovations	Timing of Project Teams' Involvement in GB Processes						
DELPHI METHOD SECOND ROUND RESULTS	Standard Deviation Regarding the Timing of Project Teams' Involvement in Schematic Design						
	Owner	General Contractor	Mechanical Team	Electrical Team	Archiectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	1,45	1,42	1,93	1,81	1,96	1,57	0,70
Site Selection	1,45	2,02	2,07	2,12	1,56	1,65	0,79
Development Density and Community Connectivity	1,64	2,02	1,85	1,85	1,37	1,23	0,79
Brownfield Redevelopment	1,66	1,81	1,91	1,85	1,72	1,43	0,79
Alternative Transportation—Public Transportation Access	1,73	1,85	1,89	1,85	1,56	1,23	0,92
Alternative Transportation—Bicycle Storage and Changing Rooms	1,45	1,73	1,85	1,87	1,17	1,23	0,92
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	1,17	1,71	1,89	1,40	1,16	1,43	0,92
Alternative Transportation—Parking Capacity	1,18	1,66	1,85	1,89	1,17	1,43	0,92
Site Development—Protect or Restore Habitat	1,34	1,64	1,85	1,70	1,10	1,17	0,99
Site Development—Maximize Open Space	1,34	1,90	1,81	1,78	1,16	1,17	0,84
Stormwater Design—Quantity Control	1,26	1,70	2,18	1,78	0,94	1,18	0,48
Stormwater Design—Quality Control	1,26	1,70	2,11	1,78	1,14	1,18	0,74
Heat Island Effect—Non-roof	1,26	1,90	2,41	1,78	1,16	1,18	1,62
Heat Island Effect—Roof	1,27	1,90	2,01	1,78	1,17	1,18	1,64
Light Pollution Reduction	1,49	1,90	2,17	2,22	1,03	1,18	1,26
Water Efficiency							
Water Use Reduction—20% Reduction	1,43	1,89	1,43	1,58	0,97	1,72	1,84
Water Efficient Landscaping	1,49	1,89	1,43	1,78	0,97	1,71	1,84
Innovative Wastewater Technologies	1,49	1,89	1,34	1,65	0,70	1,72	1,84
Water Use Reduction	1,49	1,89	1,43	1,78	0,97	1,72	1,84
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	1,29	2,16	1,32	1,14	1,48	2,54	0,88
Minimum Energy Performance	1,29	2,21	1,42	1,27	1,35	1,90	1,03
Fundamental Refrigerant Management	1,32	2,07	1,51	2,57	2,59	1,99	1,58
Optimize Energy Performance	1,33	2,27	1,18	1,49	1,35	1,73	1,57
On-Site Renewable Energy	1,32	2,08	1,99	1,26	1,97	2,23	1,51
Enhanced Commissioning	1,32	2,15	1,32	2,12	2,28	2,59	1,51
Enhanced Refrigerant Management	1,32	2,01	1,51	2,32	2,88	2,17	1,93
Measurement and Verification	1,34	2,05	1,20	0,67	2,63	2,25	1,66
Green Power	1,25	2,32	2,57	1,83	2,88	2,21	2,10
Materials and Resources							
Storage and Collection of Recyclables	0,97	2,60	2,21	1,95	0,74	1,81	1,91
Building Reuse—Maintain Existing Walls, Floors, and Roof	0,99	1,75	1,96	1,87	0,82	1,70	1,95
Building Reuse—Maintain 50% of Interior Non-Structural Elements	1,05	1,75	1,90	2,00	0,88	1,58	1,95
Construction Waste Management	1,27	1,55	1,89	1,96	2,17	2,32	2,18
Materials Reuse	1,35	1,52	2,12	1,97	1,18	1,79	2,18
Recycled Content	1,26	2,02	2,07	1,94	1,23	1,79	1,66
Regional Materials	0,95	2,02	2,17	1,94	1,17	1,79	1,66
Rapidly Renewable Materials	1,26	2,02	2,07	1,94	1,17	1,79	1,66
Certified Wood	0,97	1,49	2,01	1,85	1,17	1,79	1,66
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	1,52	2,07	1,25	2,37	2,46	1,79	1,45
Environmental Tobacco Smoke (ETS) Control	1,49	2,30	1,51	2,15	1,89	2,39	1,62
Outdoor Air Delivery Monitoring	1,37	2,00	1,17	1,95	2,41	2,17	0,97
Increased Ventilation	1,52	1,99	1,23	2,08	2,41	2,01	1,26
Construction IAQ Management Plan—During Construction	1,49	2,16	2,02	1,75	2,47	2,45	2,00
Construction IAQ Management Plan—Before Occupancy	1,49	2,40	1,52	2,08	2,63	2,64	1,90
Low-Emitting Materials—Adhesives and Sealants	1,40	2,17	1,56	2,12	1,43	2,22	2,08
Low-Emitting Materials—Paints and Coatings	1,40	2,17	2,16	2,12	1,43	2,17	2,18
Low-Emitting Materials—Flooring Systems	1,40	2,17	2,39	2,16	1,34	2,17	2,18
Low-Emitting Materials—Composite Wood and Agrifiber Products	1,40	2,17	2,47	2,22	1,34	2,17	2,18
Indoor Chemical and Pollutant Source Control	1,41	1,96	0,92	2,08	1,42	1,99	1,78
Controllability of Systems—Lighting	1,37	2,00	2,26	1,42	1,85	1,96	1,73
Controllability of Systems—Thermal Comfort	1,37	1,93	1,08	2,39	1,89	1,90	1,65
Thermal Comfort—Design	1,37	2,05	1,08	2,00	2,68	1,90	1,83
Thermal Comfort—Verification	1,42	2,41	1,81	2,00	2,83	1,90	1,84
Daylight and Views—Daylight	1,51	2,44	2,70	2,08	1,40	1,83	1,73
Daylight and Views—Views	1,51	2,45	2,67	2,17	1,42	1,95	1,42

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Conctruction and Major Renovations	Timing of Project Teams' Involvement in GB Processes						
	Mean Values Regarding the Design Development Phase (Including Design Development and Construction documentation)						
DELPHI METHOD SECOND ROUND RESULTS	1 - Without any importance 3 - Moderate importance 5 - Strong importance 7 - Highly important 9 - Extreme importance 2, 4, 6, 8 points refer to the importance level between level represented above.						
	Owner	General Contractor	Mechanical Team	Electrical Team	Archiectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	7,10	5,70	4,10	3,20	6,50	4,80	3,90
Site Selection	7,40	5,10	3,70	2,90	6,90	3,10	3,50
Development Density and Community Connectivity	7,40	4,00	3,60	3,00	6,70	3,10	3,00
Brownfield Redevelopment	7,50	5,30	3,80	3,10	6,40	3,10	3,60
Alternative Transportation—Public Transportation Access	7,10	4,50	3,50	2,90	6,70	3,10	3,10
Alternative Transportation—Bicycle Storage and Changing Rooms	7,20	5,00	3,70	3,00	7,30	3,10	3,30
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	7,50	5,40	3,80	4,60	6,80	3,10	3,40
Alternative Transportation—Parking Capacity	7,60	5,10	3,40	3,00	6,80	3,40	3,00
Site Development—Protect or Restore Habitat	7,60	5,70	3,40	3,10	7,50	3,10	3,40
Site Development—Maximize Open Space	7,60	5,60	3,40	3,10	7,50	3,10	3,40
Stormwater Design—Quantity Control	7,30	5,60	7,00	4,00	7,30	3,10	4,50
Stormwater Design—Quality Control	7,30	5,60	7,00	3,90	7,30	3,20	4,30
Heat Island Effect—Non-roof	7,30	5,60	4,70	3,60	7,60	3,20	4,90
Heat Island Effect—Roof	7,30	5,60	4,60	3,80	7,60	3,10	4,90
Light Pollution Reduction	7,30	5,60	3,50	6,60	7,20	3,10	5,10
Water Efficiency							
Water Use Reduction—20% Reduction	7,70	6,30	7,50	3,80	7,40	3,90	6,50
Water Efficient Landscaping	7,70	6,30	7,50	3,60	7,60	3,90	6,10
Innovative Wastewater Technologies	7,70	6,50	7,50	3,70	7,50	3,90	6,80
Water Use Reduction	7,70	6,30	7,50	3,60	7,50	3,90	6,80
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	7,70	6,60	7,60	6,90	6,20	5,60	5,70
Minimum Energy Performance	7,70	6,70	7,80	7,50	7,50	4,60	6,40
Fundamental Refrigerant Management	7,70	6,70	7,70	4,60	5,40	4,50	6,40
Optimize Energy Performance	7,80	6,70	8,00	7,60	7,50	4,60	6,30
On-Site Renewable Energy	7,90	6,60	7,20	7,60	6,60	4,80	6,40
Enhanced Commissioning	7,80	6,60	7,60	6,30	5,50	5,40	5,80
Enhanced Refrigerant Management	7,70	6,60	7,60	4,40	4,70	4,60	6,10
Measurement and Verification	7,70	6,40	7,40	7,00	4,80	4,80	5,80
Green Power	7,90	5,70	6,10	6,90	4,40	4,00	5,60
Materials and Resources							
Storage and Collection of Recyclables	7,50	5,30	3,70	3,20	7,70	5,00	3,90
Building Reuse—Maintain Existing Walls, Floors, and Roof	8,10	5,70	3,90	3,40	8,00	5,40	3,70
Building Reuse—Maintain 50% of Interior Non-Structural Elements	8,10	5,10	3,90	3,40	8,00	5,40	3,70
Construction Waste Management	7,40	7,40	4,70	3,90	6,00	6,00	3,70
Materials Reuse	7,70	6,70	3,70	3,20	7,70	5,10	5,20
Recycled Content	7,70	6,80	3,80	3,40	7,90	5,10	7,00
Regional Materials	7,70	6,80	3,80	3,50	7,90	5,10	7,00
Rapidly Renewable Materials	7,70	6,80	3,80	3,30	7,90	5,10	7,00
Certified Wood	7,70	6,80	3,80	3,20	7,90	5,10	6,90
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	6,80	5,70	8,20	5,00	5,90	3,60	5,10
Environmental Tobacco Smoke (ETS) Control	7,40	6,20	7,20	4,90	6,20	4,60	4,80
Outdoor Air Delivery Monitoring	7,30	6,00	8,00	5,00	5,70	4,10	5,00
Increased Ventilation	6,90	6,00	8,30	5,00	5,70	3,80	5,10
Construction IAQ Management Plan—During Construction	7,00	7,20	7,40	5,30	5,20	4,80	4,40
Construction IAQ Management Plan—Before Occupancy	7,00	7,20	7,60	4,80	5,00	4,60	4,40
Low-Emitting Materials—Adhesives and Sealants	7,00	6,70	6,00	5,20	6,80	5,00	6,90
Low-Emitting Materials—Paints and Coatings	7,00	6,70	5,20	5,20	6,80	5,00	6,90
Low-Emitting Materials—Flooring Systems	7,00	6,70	4,20	4,00	6,80	5,00	7,10
Low-Emitting Materials—Composite Wood and Agrifiber Products	7,00	6,70	4,20	4,00	6,80	5,00	7,10
Indoor Chemical and Pollutant Source Control	7,20	6,50	6,80	4,70	7,00	4,70	6,20
Controllability of Systems—Lighting	7,20	6,00	4,40	7,30	6,60	4,30	4,70
Controllability of Systems—Thermal Comfort	7,20	6,00	7,70	5,40	6,60	4,30	5,20
Thermal Comfort—Design	7,20	5,70	8,00	4,50	6,20	4,30	4,80
Thermal Comfort—Verification	7,50	5,50	8,00	4,40	5,70	4,30	4,80
Daylight and Views—Daylight	7,30	5,50	4,50	6,00	7,10	4,20	4,60
Daylight and Views—Views	7,30	5,30	5,00	4,60	7,20	4,20	4,50

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Conctruction and Major Renovations	Timing of Project Teams' Involvement in GB Processes						
DELPHI METHOD SECOND ROUND RESULTS	Standard Deviation Regarding the Design Development Phase (Including Design Development and Construction documentation)						
	Owner	General Contractor	Mechanical Team	Electrical Team	Archiectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	1,52	2,00	2,42	2,25	2,12	2,25	2,28
Site Selection	1,58	2,47	2,45	2,33	1,85	1,66	2,37
Development Density and Community Connectivity	1,58	2,58	2,50	2,31	2,06	1,66	2,31
Brownfield Redevelopment	1,35	2,50	2,62	2,33	1,96	1,66	2,41
Alternative Transportation—Public Transportation Access	1,73	2,46	2,59	2,47	2,06	1,66	2,23
Alternative Transportation—Bicycle Storage and Changing Rooms	1,40	2,21	2,26	2,36	1,25	1,66	2,21
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	1,27	2,12	2,44	1,90	1,40	1,66	2,37
Alternative Transportation—Parking Capacity	1,26	2,23	2,41	2,31	1,40	1,71	2,21
Site Development—Protect or Restore Habitat	1,43	2,26	2,41	2,38	1,27	1,66	2,37
Site Development—Maximize Open Space	1,43	2,32	2,41	2,38	1,27	1,66	2,41
Stormwater Design—Quantity Control	1,42	2,17	1,70	2,49	1,42	1,66	2,01
Stormwater Design—Quality Control	1,42	2,17	1,70	2,56	1,42	1,62	2,21
Heat Island Effect—Non-roof	1,42	2,32	2,26	2,41	1,17	1,62	1,97
Heat Island Effect—Roof	1,42	2,32	2,27	2,30	1,17	1,66	1,97
Light Pollution Reduction	1,57	2,32	2,51	2,01	1,14	1,66	2,18
Water Efficiency							
Water Use Reduction—20% Reduction	1,06	1,70	1,18	2,20	1,43	1,52	1,65
Water Efficient Landscaping	1,06	1,70	1,18	2,37	0,97	1,52	1,73
Innovative Wastewater Technologies	1,06	1,65	1,18	2,26	1,43	1,52	1,40
Water Use Reduction	1,06	1,70	1,18	2,37	1,43	1,52	1,40
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	1,16	1,78	1,58	1,29	1,62	2,27	1,70
Minimum Energy Performance	1,16	1,77	1,62	1,27	1,35	1,78	1,43
Fundamental Refrigerant Management	1,25	1,77	1,64	2,80	2,67	1,90	1,43
Optimize Energy Performance	1,23	1,77	1,33	1,35	1,35	1,78	1,42
On-Site Renewable Energy	1,29	1,78	2,20	1,35	1,96	1,69	1,43
Enhanced Commissioning	1,23	1,78	1,58	1,95	2,42	2,22	1,75
Enhanced Refrigerant Management	1,25	1,78	1,58	2,46	2,87	1,78	1,45
Measurement and Verification	1,16	1,84	1,51	0,94	2,78	1,75	1,81
Green Power	1,20	2,63	2,81	2,08	2,84	2,16	2,12
Materials and Resources							
Storage and Collection of Recyclables	1,18	2,54	2,41	2,30	0,82	1,70	2,18
Building Reuse—Maintain Existing Walls, Floors, and Roof	0,88	2,36	2,23	2,37	0,94	1,43	2,31
Building Reuse—Maintain 50% of Interior Non-Structural Elements	0,88	2,18	2,23	2,37	0,94	1,43	2,31
Construction Waste Management	1,26	2,12	2,11	2,18	2,45	1,63	2,31
Materials Reuse	1,25	1,77	2,41	2,30	1,25	1,52	2,44
Recycled Content	0,82	1,81	2,35	2,32	1,29	1,52	1,70
Regional Materials	0,82	1,81	2,35	2,42	1,29	1,52	1,70
Rapidly Renewable Materials	0,82	1,81	2,35	2,26	1,29	1,52	1,70
Certified Wood	0,82	1,81	2,35	2,25	1,29	1,52	1,60
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	1,55	2,06	1,32	2,11	2,13	1,51	2,18
Environmental Tobacco Smoke (ETS) Control	1,65	1,81	1,62	2,08	1,81	1,90	2,10
Outdoor Air Delivery Monitoring	1,57	1,83	1,33	2,16	2,16	1,85	2,21
Increased Ventilation	1,60	1,83	1,34	2,16	2,36	1,55	2,18
Construction IAQ Management Plan—During Construction	1,76	1,75	1,51	2,11	2,35	2,25	2,50
Construction IAQ Management Plan—Before Occupancy	1,76	1,75	1,26	1,99	2,45	2,32	2,50
Low-Emitting Materials—Adhesives and Sealants	1,76	1,57	1,76	2,04	1,62	1,70	1,85
Low-Emitting Materials—Paints and Coatings	1,76	1,57	2,39	2,04	1,62	1,70	1,85
Low-Emitting Materials—Flooring Systems	1,76	1,57	2,70	2,40	1,62	1,70	1,73
Low-Emitting Materials—Composite Wood and Agrifiber Products	1,76	1,57	2,70	2,40	1,62	1,70	1,73
Indoor Chemical and Pollutant Source Control	1,48	1,65	1,32	2,00	1,33	1,57	2,04
Controllability of Systems—Lighting	1,48	1,89	2,63	1,83	1,84	1,34	2,26
Controllability of Systems—Thermal Comfort	1,48	1,89	1,25	2,07	1,84	1,34	2,39
Thermal Comfort—Design	1,48	2,06	1,33	2,17	2,25	1,34	2,30
Thermal Comfort—Verification	1,35	2,22	1,33	2,12	2,45	1,34	2,30
Daylight and Views—Daylight	1,34	2,42	2,68	1,70	1,20	1,48	2,32
Daylight and Views—Views	1,34	2,54	2,58	2,27	1,23	1,48	2,22

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

LEED® 2009 for New Construction and Major Renovations	Timing of Project Teams' Involvement in GB Processes						
	Mean Values Regarding the Timing of Project Teams' Involvement in Construction (including Construction Administration)						
DELPHI METHOD SECOND ROUND RESULTS	1 - Without any importance 3 - Moderate importance 5 - Strong importance 7 - Highly important 9 - Extreme importance 2, 4, 6, 8 points refer to the importance level between level represented above.						
	Owner	General Contractor	Mechanical Team	Electrical Team	Archiectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	7,30	6,90	4,40	4,00	6,90	7,00	4,00
Site Selection	6,80	4,90	3,10	2,90	6,50	4,70	3,30
Development Density and Community Connectivity	6,80	4,70	3,10	3,00	6,50	4,70	2,90
Brownfield Redevelopment	7,20	6,50	3,60	3,40	6,40	6,20	3,80
Alternative Transportation—Public Transportation Access	6,70	4,70	3,00	3,00	6,60	4,80	2,90
Alternative Transportation—Bicycle Storage and Changing Rooms	6,70	5,20	3,50	2,90	6,90	4,90	3,20
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	6,90	5,80	3,00	4,20	6,90	4,90	3,80
Alternative Transportation—Parking Capacity	6,70	5,20	3,10	3,00	6,70	4,90	2,90
Site Development—Protect or Restore Habitat	7,00	6,30	3,50	3,60	6,80	5,90	3,60
Site Development—Maximize Open Space	7,00	6,10	3,20	3,20	6,80	5,90	3,30
Stormwater Design—Quantity Control	6,80	6,40	5,50	3,70	6,60	6,30	4,20
Stormwater Design—Quality Control	6,80	6,40	5,90	3,60	6,60	6,30	4,20
Heat Island Effect—Non-roof	6,80	6,00	4,80	3,60	6,70	6,00	4,00
Heat Island Effect—Roof	6,80	6,00	4,70	3,60	6,70	6,00	4,00
Light Pollution Reduction	6,60	5,80	3,90	5,40	6,70	5,10	4,00
Water Efficiency							
Water Use Reduction—20% Reduction	7,00	6,20	6,80	3,60	6,30	6,20	6,30
Water Efficient Landscaping	7,00	6,20	6,80	3,60	6,10	6,10	6,60
Innovative Wastewater Technologies	6,80	6,20	6,80	3,60	6,20	6,10	6,70
Water Use Reduction	6,80	6,20	6,80	3,60	6,30	5,90	6,60
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	7,10	6,80	7,30	7,10	5,70	7,30	6,00
Minimum Energy Performance	7,10	6,90	7,20	7,50	6,40	6,90	6,20
Fundamental Refrigerant Management	7,20	6,80	7,40	4,70	5,00	6,40	6,20
Optimize Energy Performance	7,10	6,80	7,30	7,50	6,50	6,60	6,20
On-Site Renewable Energy	7,20	6,70	6,50	7,50	6,30	6,60	6,20
Enhanced Commissioning	7,20	6,70	7,10	6,40	5,20	7,20	6,00
Enhanced Refrigerant Management	7,20	6,70	7,60	4,70	4,80	6,30	6,20
Measurement and Verification	7,10	6,40	7,00	7,20	4,80	6,60	6,10
Green Power	7,30	5,30	5,40	6,80	5,00	5,50	5,90
Materials and Resources							
Storage and Collection of Recyclables	6,80	5,60	3,80	3,00	7,40	6,50	5,20
Building Reuse—Maintain Existing Walls, Floors, and Roof	7,30	6,80	4,10	3,30	7,70	7,10	5,20
Building Reuse—Maintain 50% of Interior Non-Structural Elements	7,30	6,80	4,10	3,30	7,70	7,10	5,20
Construction Waste Management	6,90	7,80	4,40	3,60	6,80	7,40	5,20
Materials Reuse	6,90	6,80	3,80	3,00	7,40	7,10	5,90
Recycled Content	7,10	6,80	3,80	3,00	7,50	6,90	6,60
Regional Materials	7,10	6,80	3,80	3,10	7,40	6,90	6,70
Rapidly Renewable Materials	7,10	6,80	3,80	3,10	7,40	6,90	6,70
Certified Wood	7,10	6,80	3,80	2,90	7,40	6,90	6,70
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	6,80	5,50	7,30	4,40	6,00	5,60	5,10
Environmental Tobacco Smoke (ETS) Control	6,80	6,20	6,40	4,40	6,20	6,40	5,10
Outdoor Air Delivery Monitoring	6,80	5,70	7,10	4,60	5,90	6,50	5,00
Increased Ventilation	6,80	5,70	7,40	4,20	5,90	6,00	4,90
Construction IAQ Management Plan—During Construction	6,20	6,70	7,30	4,70	6,00	7,60	4,50
Construction IAQ Management Plan—Before Occupancy	6,20	6,70	7,30	4,60	6,00	7,40	4,60
Low-Emitting Materials—Adhesives and Sealants	6,40	6,40	6,10	5,10	6,80	6,80	7,00
Low-Emitting Materials—Paints and Coatings	6,40	6,40	5,00	4,80	6,90	6,80	7,00
Low-Emitting Materials—Flooring Systems	6,40	6,30	4,70	4,60	6,90	6,80	6,80
Low-Emitting Materials—Composite Wood and Agrifiber Products	6,40	6,30	4,70	4,60	6,90	6,80	6,80
Indoor Chemical and Pollutant Source Control	6,60	6,10	6,40	4,90	6,70	6,70	6,20
Controllability of Systems—Lighting	6,60	5,80	4,50	7,80	6,40	6,10	4,90
Controllability of Systems—Thermal Comfort	6,60	5,80	8,00	4,80	6,20	6,00	5,10
Thermal Comfort—Design	6,70	5,60	7,90	4,50	5,50	5,60	5,10
Thermal Comfort—Verification	7,00	5,60	7,60	4,60	5,30	5,40	4,80
Daylight and Views—Daylight	6,90	5,20	4,60	5,40	7,10	5,30	5,10
Daylight and Views—Views	6,90	5,20	4,20	4,50	7,10	5,30	4,90

Certified 40 to 49 points   Silver 50 to 59 points
Gold 60 to 79 points   Platinum 80 to 110 points

LEED® 2009 for New Construction and Major Renovations	Timing of Project Teams' Involvement in GB Processes						
DELPHI METHOD SECOND ROUND RESULTS	Standard Deviation Regarding the Timing of Project Teams' Involvement in Construction (including Constr. Administration)						
	Owner	General Contractor	Mechanical Team	Electrical Team	Archiectural Team	Civil Team	Material Suppliers
Sustainable Sites							
Construction Activity Pollution Prevention	1,57	1,45	2,37	2,31	1,29	1,33	2,16
Site Selection	2,20	2,13	2,47	2,38	1,90	2,83	2,50
Development Density and Community Connectivity	2,20	2,11	2,47	2,40	1,90	2,83	2,33
Brownfield Redevelopment	1,55	2,22	2,41	2,37	1,71	2,53	2,25
Alternative Transportation—Public Transportation Access	2,16	2,11	2,40	2,40	2,01	2,49	2,33
Alternative Transportation—Bicycle Storage and Changing Rooms	1,49	2,10	2,42	2,42	1,60	2,51	2,30
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	1,37	1,62	2,40	2,15	1,60	2,51	2,39
Alternative Transportation—Parking Capacity	2,00	2,10	2,42	2,40	1,77	2,51	2,33
Site Development—Protect or Restore Habitat	1,70	1,70	2,37	2,50	1,55	2,33	2,37
Site Development—Maximize Open Space	1,70	1,79	2,35	2,39	1,55	2,33	2,50
Stormwater Design—Quantity Control	1,55	1,84	1,90	2,31	1,35	1,42	2,15
Stormwater Design—Quality Control	1,55	1,84	1,79	2,37	1,35	1,42	2,15
Heat Island Effect—Non-roof	1,55	1,70	2,15	2,37	1,42	1,63	2,26
Heat Island Effect—Roof	1,55	1,70	2,16	2,37	1,42	1,63	2,26
Light Pollution Reduction	1,65	1,69	2,47	2,17	1,42	2,38	2,26
Water Efficiency							
Water Use Reduction—20% Reduction	1,83	1,93	1,40	2,27	1,64	2,10	1,42
Water Efficient Landscaping	1,83	1,93	1,40	2,27	1,60	2,08	1,43
Innovative Wastewater Technologies	1,69	1,93	1,40	2,27	1,75	2,08	1,42
Water Use Reduction	1,69	1,93	1,40	2,27	1,64	2,08	1,35
Energy and Atmosphere							
Fundamental Commissioning of Building Energy Systems	1,60	1,23	1,57	1,45	1,57	1,25	1,56
Minimum Energy Performance	1,60	1,20	1,48	1,35	1,65	1,29	1,40
Fundamental Refrigerant Management	1,69	1,14	1,58	2,83	2,00	1,96	1,40
Optimize Energy Performance	1,60	1,14	1,16	1,35	1,58	1,26	1,40
On-Site Renewable Energy	1,69	1,16	1,96	1,35	1,77	1,26	1,40
Enhanced Commissioning	1,69	1,16	1,45	2,01	1,93	1,23	1,56
Enhanced Refrigerant Management	1,69	1,16	1,71	2,95	2,35	1,70	1,40
Measurement and Verification	1,60	1,26	1,41	1,40	2,35	1,26	1,52
Green Power	1,49	2,36	2,41	2,04	2,67	2,51	1,91
Materials and Resources							
Storage and Collection of Recyclables	1,75	2,12	2,35	2,26	0,84	2,01	2,35
Building Reuse—Maintain Existing Walls, Floors, and Roof	1,49	1,87	2,28	2,31	0,95	1,10	2,35
Building Reuse—Maintain 50% of Interior Non-Structural Elements	1,49	1,87	2,28	2,31	0,95	1,10	2,35
Construction Waste Management	1,52	1,23	2,37	2,50	2,10	0,97	2,35
Materials Reuse	1,52	1,32	2,35	2,26	1,17	1,10	1,85
Recycled Content	1,37	1,32	2,35	2,26	1,27	1,45	1,78
Regional Materials	1,37	1,32	2,35	2,33	1,17	1,45	1,77
Rapidly Renewable Materials	1,37	1,32	2,35	2,33	1,17	1,45	1,77
Certified Wood	1,37	1,32	2,35	2,23	1,17	1,45	1,77
Indoor Environmental Quality							
Minimum Indoor Air Quality Performance	1,81	1,78	1,42	2,32	1,94	1,96	2,18
Environmental Tobacco Smoke (ETS) Control	1,81	1,62	1,71	2,27	1,81	1,43	2,18
Outdoor Air Delivery Monitoring	1,81	1,57	1,10	2,07	1,91	1,51	2,21
Increased Ventilation	1,81	1,57	1,35	2,30	1,91	1,49	2,28
Construction IAQ Management Plan—During Construction	1,87	1,42	1,49	2,06	2,05	1,35	2,59
Construction IAQ Management Plan—Before Occupancy	1,87	1,42	1,25	2,22	2,05	1,43	2,50
Low-Emitting Materials—Adhesives and Sealants	1,78	1,26	1,29	1,97	1,32	1,03	1,49
Low-Emitting Materials—Paints and Coatings	1,78	1,26	2,16	2,04	1,29	1,03	1,49
Low-Emitting Materials—Flooring Systems	1,78	1,42	2,06	2,07	1,29	1,03	1,62
Low-Emitting Materials—Composite Wood and Agrifiber Products	1,78	1,42	2,06	2,07	1,29	1,03	1,62
Indoor Chemical and Pollutant Source Control	1,84	1,29	1,35	1,97	1,34	1,06	1,69
Controllability of Systems—Lighting	1,84	1,40	2,32	1,32	1,96	1,29	2,08
Controllability of Systems—Thermal Comfort	1,84	1,40	1,25	2,15	1,75	1,33	2,33
Thermal Comfort—Design	1,83	1,65	1,37	2,17	2,55	2,07	2,33
Thermal Comfort—Verification	1,76	1,65	1,65	2,22	2,45	2,22	2,62
Daylight and Views—Daylight	1,85	2,15	2,41	2,27	1,10	2,21	2,08
Daylight and Views—Views	1,85	2,15	2,35	2,46	1,10	2,21	2,08

Certified 40 to 49 points Silver 50 to 59 points
Gold 60 to 79 points Platinum 80 to 110 points

APPENDIX B

Results of TOPSIS within the Green Building-Credit Selection Model based on Improved Attributes of Green Building Project Delivery

Use of the Green Building-Credit Selection Model to Determine Appropriate Credits for GB Certification based on Improved Attributes of Green Building Project Delivery				
Ci* = Si / (Si' + Si*) 0<Ci*<1 , i= 1,2,...,m Ci* = 1 if and only if the alternative is the best alternative Ci* = 0 if and only if the alternative is the worst alternative	Separation Measures PIS (Si^+), and NIS (Si^-)		Relative Closeness	Preference Order according to Ci*
Credits categorized under LEED® 2009 for New Construction and Major Renovations Rating System	S_i* (distance from the positive ideal solution)	S_i' (distance from the negative ideal solution)	Ci* 0<Ci*<1	Rank
Sustainable Sites				
Construction Activity Pollution Prevention	0,0216475436	0,0167395466	0,4360722964	24
Site Selection	0,0189290672	0,0215380241	0,5322355377	14
Development Density and Community Connectivity	0,0174303080	0,0220917685	0,5589728693	12
Brownfield Redevelopment	0,0306553332	0,0016528637	0,0511592689	54
Alternative Transportation—Public Transportation Access	0,0189505399	0,0212529022	0,5286338958	15
Alternative Transportation—Bicycle Storage and Changing Rooms	0,0151563946	0,0200696103	0,5697384751	11
Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	0,0239936836	0,0156182094	0,3942808140	34
Alternative Transportation—Parking Capacity	0,0294483014	0,0075399057	0,2038462074	50
Site Development—Protect or Restore Habitat	0,0121750454	0,0242500377	0,6657510600	7
Site Development—Maximize Open Space	0,0286595941	0,0076978521	0,2117269762	47
Stormwater Design—Quantity Control	0,0287071927	0,0075906902	0,2091221193	48
Stormwater Design—Quality Control	0,0287071927	0,0075906902	0,2091221193	49
Heat Island Effect—Non-roof	0,0228348157	0,0157892577	0,4087931775	31
Heat Island Effect—Roof	0,0228881833	0,0154507857	0,4030047260	33
Light Pollution Reduction	0,0293182709	0,0080306676	0,2150172915	43
Water Efficiency				
Water Use Reduction—20% Reduction	0,0217839674	0,0161778117	0,4261605252	27
Water Efficient Landscaping	0,0221138734	0,0174060146	0,4404368392	23
Innovative Wastewater Technologies	0,0227679786	0,0154895247	0,4048754718	32
Water Use Reduction	0,0217839674	0,0161778117	0,4261605252	28
Energy and Atmosphere				
Fundamental Commissioning of Building Energy Systems	0,0115910357	0,0265193760	0,6958564544	3
Minimum Energy Performance	0,0106030657	0,0266225295	0,7151673303	1
Fundamental Refrigerant Management	0,0127435779	0,0253300224	0,6652909682	8
Optimize Energy Performance	0,0106030657	0,0266225295	0,7151673303	2
On-Site Renewable Energy	0,0296081464	0,0059634392	0,1676461457	52
Enhanced Commissioning	0,0239858297	0,0189199391	0,4409649239	22
Enhanced Refrigerant Management	0,0128168905	0,0252682975	0,6634678413	10
Measurement and Verification	0,0251524957	0,0157009564	0,3843238592	37
Green Power	0,0296081464	0,0059634392	0,1676461457	53
Materials and Resources				
Storage and Collection of Recyclables	0,0212039786	0,0178333841	0,4568286082	16
Building Reuse—Maintain Existing Walls, Floors, and Roof	0,0297034371	0,0080346851	0,2129063305	44
Building Reuse—Maintain 50% of Interior Non-Structural Elements	0,0297034371	0,0080346851	0,2129063305	45
Construction Waste Management	0,0228013816	0,0139056726	0,3788283448	39
Materials Reuse	0,0241649100	0,0157124970	0,3940200266	35
Recycled Content	0,0241649100	0,0157124970	0,3940200266	36
Regional Materials	0,0239078086	0,0170746829	0,4166335983	29
Rapidly Renewable Materials	0,0217816426	0,0180332496	0,4529272489	17
Certified Wood	0,0287333891	0,0077333456	0,2120657539	46
Indoor Environmental Quality				
Minimum Indoor Air Quality Performance	0,0225201768	0,0170664152	0,4311160509	25
Environmental Tobacco Smoke (ETS) Control	0,0183665382	0,0215112227	0,5394290506	13
Outdoor Air Delivery Monitoring	0,0296743870	0,0065830478	0,1815640803	51
Increased Ventilation	0,0215868320	0,0175744601	0,4487712019	18
Construction IAQ Management Plan—During Construction	0,0220527026	0,0175192957	0,4427195099	21
Construction IAQ Management Plan—Before Occupancy	0,0253270523	0,0153289688	0,3770405563	40
Low-Emitting Materials—Adhesives and Sealants	0,0205142804	0,0165102250	0,4459269556	19
Low-Emitting Materials—Paints and Coatings	0,0205142804	0,0165102250	0,4459269556	20
Low-Emitting Materials—Flooring Systems	0,0216012290	0,0163109749	0,4302301955	26
Low-Emitting Materials—Composite Wood and Agrifiber Products	0,0280327507	0,0084928222	0,2325171527	42
Indoor Chemical and Pollutant Source Control	0,0271966346	0,0093374938	0,2555827721	41
Controllability of Systems—Lighting	0,0131219244	0,0259034254	0,6637589552	9
Controllability of Systems—Thermal Comfort	0,0128376252	0,0260454934	0,6698406488	6
Thermal Comfort—Design	0,0230780237	0,0160959097	0,4108831640	30
Thermal Comfort—Verification	0,0247851507	0,0154108157	0,3833920936	38
Daylight and Views—Daylight	0,0127804215	0,0264796681	0,6744678476	4
Daylight and Views—Views	0,0127804215	0,0264796681	0,6744678476	5

The Output of the Green Building-Credit Selection Model Based on Improved Attributes of GB Project Delivery

LEED® Ceritification Levels	Evaluation Scale	Rank	Ci* (relative closeness)	Ranking List of LEED® 2009 NC Environmental Credits based on Project Delivery Attributes	Environmental Points	Add Cost Ratio for LEED Silver Certificate (Stegall, 2004)	Add Cost Ratio for LEED Silver Certificate (GSA, 2004)	Additional Cost Ratio for LEED Gold Cerificate (GSA, 2004)
CERTIFIED* SILVER** GOLD*** PLATINUM****		1	0,7152	Minimum Energy Performance	Prerequisite	N/A	N/A	N/A
		2	0,7152	Optimize Energy Performance	1 to 19	0,183%	0,040%	0,040%
	YES	3	0,6959	Fundamental Commissioning of Building Energy Systems	Prerequisite	0,398%	N/A	N/A
		4	0,6745	Daylight and Views—Daylight	1	N/A	N/A	N/A
		5	0,6745	Daylight and Views—Views	1	N/A	N/A	N/A
		6	0,6698	Controllability of Systems—Thermal Comfort	1	N/A	N/A	N/A
		7	0,6658	Site Development—Protect or Restore Habitat	1	N/A	N/A	N/A
		8	0,6653	Fundamental Refrigerant Management	Prerequisite	N/A	N/A	N/A
		9	0,6638	Controllability of Systems—Lighting	1	N/A	N/A	N/A
		10	0,6635	Enhanced Refrigerant Management	2	N/A	N/A	N/A
		11	0,5697	Alternative Transportation—Bicycle Storage and Changing Rooms	1	N/A	N/A	0,017%
		12	0,5590	Development Density and Community Connectivity	5	N/A	N/A	N/A
		13	0,5394	Environmental Tobacco Smoke (ETS) Control	Prerequisite	N/A	N/A	N/A
		14	0,5322	Site Selection	1	N/A	N/A	N/A
		15	0,5286	Alternative Transportation—Public Transportation Access	6	N/A	N/A	N/A
		16	0,4568	Storage and Collection of Recyclables	Prerequisite	N/A	N/A	N/A
		17	0,4529	Rapidly Renewable Materials	1	N/A	N/A	N/A
		18	0,4488	Increased Ventilation	1	N/A	N/A	N/A
		19	0,4459	Low-Emitting Materials—Adhesives and Sealants	1	0,003%	N/A	N/A
	MAYBE	20	0,4459	Low-Emitting Materials—Paints and Coatings	1	0,033%	N/A	N/A
		21	0,4427	Construction IAQ Management Plan—During Construction	1	0,171%	N/A	N/A
		22	0,4410	Enhanced Commissioning	2	0,120%	N/A	N/A
		23	0,4404	Water Efficient Landscaping	2 to 4	N/A	N/A	N/A
		24	0,4361	Construction Activity Pollution Prevention	Prerequisite	N/A	N/A	N/A
		25	0,4311	Minimum Indoor Air Quality Performance	Prerequisite	0,797%	N/A	N/A
		26	0,4302	Low-Emitting Materials—Flooring Systems	1	N/A	N/A	N/A
		27	0,4262	Water Use Reduction—20% Reduction	Prerequisite	N/A	N/A	N/A
		28	0,4262	Water Use Reduction	2 to 4	N/A	N/A	N/A
		29	0,4166	Regional Materials	1 to 2	N/A	N/A	N/A
		30	0,4109	Thermal Comfort—Design	1	0,076%	N/A	N/A
		31	0,4088	Heat Island Effect—Non-roof	1	0,033%	N/A	N/A
		32	0,4049	Innovative Wastewater Technologies	2	N/A	N/A	N/A
		33	0,4030	Heat Island Effect—Roof	1	0,108%	N/A	0,010%
		34	0,3943	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3	N/A	N/A	N/A
		35	0,3940	Materials Reuse	1 to 2	N/A	N/A	N/A
		36	0,3940	Recycled Content	1 to 2	N/A	N/A	N/A
		37	0,3843	Measurement and Verification	3	0,135%	0,018%	0,018%
		38	0,3834	Thermal Comfort—Verification	1	N/A	N/A	N/A
		39	0,3788	Construction Waste Management	1 to 2	N/A	N/A	N/A
		40	0,3770	Construction IAQ Management Plan—Before Occupancy	1	N/A	N/A	N/A
		41	0,2556	Indoor Chemical and Pollutant Source Control	1	N/A	N/A	N/A
	NO	42	0,2325	Low-Emitting Materials—Composite Wood and Agrifiber Products	1	0,038%	N/A	N/A
		43	0,2150	Light Pollution Reduction	1	N/A	N/A	N/A
		44	0,2129	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3	N/A	N/A	N/A
		45	0,2129	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1	N/A	N/A	N/A
		46	0,2121	Certified Wood	1	0,158%	N/A	N/A
		47	0,2117	Site Development—Maximize Open Space	1	N/A	N/A	N/A
		48	0,2091	Stormwater Design—Quantity Control	1	N/A	N/A	N/A
		49	0,2091	Stormwater Design—Quality Control	1	N/A	N/A	0,005%
		50	0,2038	Alternative Transportation—Parking Capacity	2	N/A	N/A	N/A
		51	0,1816	Outdoor Air Delivery Monitoring	1	0,012%	0,007%	0,007%
		52	0,1676	On-Site Renewable Energy	1 to 7	N/A	N/A	0,053%
		53	0,1676	Green Power	2	N/A	N/A	N/A
		54	0,0512	Brownfield Redevelopment	1	N/A	N/A	N/A
			not included	Innovation in Design (Bonus Credits)	6			
			not included	Regional Priority (Bonus Credtis)	4			
				SUBTOTAL	**110**	**2,265%**	**0,065%**	**0,149%**
				Cost of Multiple Credits Tasks (related to personnel fees)		N/A	0,146%	0,169%
				Cost of Compilling LEED Documentation* (related to personnel fees)		0,486%	0,024%	0,028%
				Modelling to satisfy LEED (related to personnel fees)		0,064%	N/A	N/A
				Commissioning for LEED (related to personnel fees)		0,518%	N/A	N/A
				Cost of LEED Registration and Certification Fees		0,014%	0,017%	0,017%
				SUBTOTAL (Soft costs ratio directly associated with LEED personnel)		**1,068%**	**0,170%**	**0,197%**
				TOTAL	**110**	**2,766%**	**0,252%**	**0,363%**

Note 1:	*Multiple Credits tasks includes (1) feasiblity reviews charette, (2) material and systems research for LEED credits, (3) cordination of LEED "Action Items" with Design Team, (4) LEED calculations for site,water and material IEQ credits, (5) LEED credit interpretation reviews and/or submissions, (6) develoment for LEED, (7) meeting(s) ro review LEED, (8) review contractor submittals, (9) general LEED integration efforts (Architect), (10) reimbursal expenses for all design team tasks (% 0.010)
Note 2:	Add soft cost outputs of GSA (2004) used in this table was calculated based on a design team with Expert Consultant. This study calculated the same credits performed by experienced Design Team. The difference between these two calculation occur in "multiple credits tasks" and "compilling documentation" which are associated with man/hour spent for these tasks. Soft costs of compilling LEED documentation done by experienced team is %0.028 for LEED Silver and %0,035 for LEED Gold.Soft cost of multiple credits tasks done by experienced team is %0,153 for LEED Silver and LEED Gold.
Evalution Scale:	$0.66 \leq Ci^* \leq 1.00$: YES $0.33 \leq Ci^* < 0.66$: MAYBE $0.00 \leq Ci^* < 0.33$: NO
Tresholds:	Certified 40 to 49 points; Silver 50 to 59 points Gold 60 to 79 points; Platinum 80 to 110 points

BIBLIOGRAPHY

Adler, A., Armstrong, J.E., Fuller, S.K., Kalin, M., Karollides, A., Macaluso, J. and Walker, H. A (2006). *Green building: Project planning and cost estimating*, 2nd Ed., R.S. Means, Kingston, Mass.

Banawi, A.A. (2013) "Improving Construction Processes by Integrating Lean, Green, and Six-Sigma" PhD Dissertation. Department of Civil and Environmental Engineering. University of Pittsburgh.

Beheiry, S. M. A., Chong, W. K. and Has, C. T. (2006). "Examining the business impact of owner commitment to sustainability." *J. Constr. Eng. Manage.,* 132(4), 384-392.

Behzadian, M., Otaghsara, S.K., Yazdani, M. and Ignatius, J. (2012). "A state-of the-art survey of TOPSIS applications", *Experts Systems with Applications,* 39(17), 13051-13069.

Betts, M. and Lansley, P. (1993), "Construction Management and Economics: a review of the first ten years", *Construction Management and Economics,* 11(4), 221–45.

BHKR (2003)."Achieving architectural and engineering collaboration in building design." *White paper,* Burt Hill Kosar Rittelmann Associates, Butler, Pa.

Bogenstätter, U. (2000). "Prediction and optimization of life-cycle costs in early design." *Build. Res. Inf.,* 28(5/6) 376-386.

Bon, R. and Hutchinson, K. (2000). "Sustainable construction: some economic challenges." *Building Research & Information*, 28(5-6), 310-314.

Brown, B. (1968). *A methodology used for the elicitation of opinions of experts*, The Rand Corporation, Santa Monica, Calif.

Bottomley, P. A. and Doyle, J. R. (2001). "A comparison of three weight elicitation methods: good, better, and best." *Omega, The International Journal of Management Science*, 29(6), 53-560.

Cassidy, R., ed. (2003). "White paper on sustainability: a report on the green building movement" *Building Design & Construction.*

Cha, H. S. and O'Connor, J.T. (2005). "Optimizing implementation of value management processes for capital projects." *J. Constr. Eng. Manage.* 131(2) 239-251.

Chan, A. P. C., Scott, D. and Chan, A. P. L. (2004) "Factors affecting the success of a construction project*." J. Constr. Eng. Manage.,* 130(1), 153-155.

Chen, P.C., Kuo, K.N., Cheng, C.S., Lee, C.Y., Kuo, C.G. and Hsueh, K.L. (2013). "A modified Delphi Method to approach green energy competency criteria" *Int. J. of Technol. and Eng. Educ.*, 10(2), 9-22.

Chu, H.C. and Hwang, G. (2008). "A Delphi-based approach to developing expert systems with the cooperation of multiple experts." *Expert Systems with Applications*, 34(4), 2826-2840.

Chua, D. K. H., Kog, Y. C. and Loh, P. K. (1999). "Critical success factors for different project ojectives." *J. Constr. Eng. Manage*., 125(3), 142-150.

Curtis, I. A. (2004). "Valuing ecosystem goods and services: a new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes." *Ecological Economics*, 50(3-4), 163-194.

Dalkey, N.C. (1969). *The Delphi method: an experimental study of Group opinion*, Santa Monica, CA: The RAND Corporation, 1-18.

Dalkey, N.C., Rourke, D.L., Lewis, R. and Synder, D. (1972). *Studies in the quality of life*. Lexington Books, Lexington, Mass., 55-83.

De Wit, A. (1986). "Measuring project success: An illusion." *Proc., 18th Annual Seminar/Symposium, Project Management Institute*, Montreal, Canada, 13-21.

Doyle, J. R., Green, R. H. and Bottomley (1997). "Judging relative importance: Dirctrating and allocation are not equivalent." *Organizational Behaviour and Human Decision Processes*, 70(1). 65-72.

Eichholtz, P., Kok, K., and Quigley, J.M. (2013). "The economics of green building". *The Review of Economics and Statistics*, 95(1), 50-63.

Emory, W.C. and Cooper, D.R. (1991). Business research methods, Irwin, Boston.

Forbes, L.H. and Ahmed, S.M. (2011). *Modern Construction - Lean Project Delivery and Integrated Practices.* CRC Press, Taylor & Francis Group.

Geist, M. R. (2010). "Using the Delphi method to engage stakeholders: A comparison of two studies." *Evaluation and Program Planning* (Special Issue) *Challenges in Evaluation of Environmental Education Programs and Policies,* 33(2), 147-154.

Glavinich, T.E. (2008). *Contractor's guide to green building construction*. John Wiley & Sons., New Jersey.

GSA (2014). U.S. General Services Administration. <http://gsa.gov/portal/category/21600>, (accessed Feb. 25, 2015).

Gultekin, P., Mollaoglu-Korkmaz, S., Riley, D., and Leicht, R. (2013). ”Process Indicators to Track Effectiveness of High-Performance Green Building Projects.” *J. Constr. Eng. Manage.*, 139(12)

Gunhan, S. and Arditi, D. (2005a). “Factors affecting international construction.” *J. Constr. Eng. Manage.*, 131(3), 273-282.

Gunhan, S. and Arditi, D. (2005b). “International expansion decision for construction companies.” *J. Constr. Eng. Manage.*, 131(8), 928-397.

Hahs-Vaughn, D.L. (2005). “A primer for using and understanding weights with national datasets.” *Journal of Experimental Education*, 73(3), 221-248.

Hakkinen, T. and Belloni, K. (2011) “Barriers and drivers for sustainable building”. *Building Research and Information*, 39(3), 239-255.

Hall, M. and Purchase, D. (2006). “Building or bodging? Attitudes to sustainability in UK public sector housing construction development.“ *Sustainable Development*, 14(3), 205-218.

Hallowell, M.R. and Gambatese, J.A. (2010). “Qualitative research: application of the Delphi method to CEM research*.” J. Constr. Eng. Manage.*, 136(1): 99-107.

Haselbach, L. (2008). *The engineering guide to LEED-New construction: Sustainable construction for engineers*, McGraw-Hill, New York.

Hasson, F. and Keeney, S. (2011). “Enhancing rigour in the Delphi technique research.” *Technological Forecasting & Social Change*, 78(9), 1695-1704.

Hilbert, M. Miles, I. and Othmer, J. (2009). “Foresight tools for participative policy-making in intergovernmental processes in developing countries: Lessons learned from the Elacc Policy Priorities Delphi.” *Tech. Forecasting and Social Change*, 76(7), 880-896.

Horman, M. J.,Riley, D. R., Lapinsky, A. R., Korkmaz, S., Pulaski, M. H., Magent, C. S., Luo, Y., Harding, N. and Dahl, P. K. (2006). “Delivering green buildings: process improvements for sustainable construction.” *J. of Green Building*, 1(1), 123-140.

Horman, M. J., Riley, D. R., Pulaski, M. H., and Leyenmeyer, C. (2004).”Lean and green: Integrating sustainability and lean construction.” *CIB World Congress*, Toronto, Rotterdam, The Netherlands.

Huovila, P. and Koskela, L. (1998). "The contribution of the principles of Lean Construction to meet the challenges of sustainable development." *Proc. of IGLC-6th*, Guaruja, Brazil.

Hwang, B. G. and Ng, W. J. (2013)."Project management knowledge and skills for green construction: Overcoming barriers." *Int . J. of Project Manage.*, 31(2), 272-284.

Hwang, B. G. and Tan, J.S. (2010). "Green Building Project Management: Obstacles and Solutions for sustainable development," *Sustainable Development*, 20(5), 335-349.

Hwang, C.L and Yoon, K. (1981). *Multiple Attribute Decision Making: Methods and Applications*. New York: Springer-Verlag.

Jarrah, R. T. and Siddiqui, M. K. (2012). "Sustainability: Opportunities and challenges from a construction contractor's perspective." *ICSDEC 2012*, pp. 601-608.

Josephson, P.E. (2003). "Defects and defect costs in construction – a study of seven building projects in Sweden." Department of Management of Construction and Facilities, Chalmers University of Technology, SE-41296, Goteborg, Sweden.

Joshi, R., Banwet, D. K. and Shankar, R. (2011). "A Delphi-AHP-TOPSIS based benchmarking framework for performance improvement of a cold chain." *Expert Systems with Applications*, 38(8), 10170-10182.

Kasim, T., Li, H. and Rezgui, Y. (2012). BREEAM: Based Dynamic Sustainable Building Design Assessment. *EG-ICE 2012*, Munich, Germany,4-6 July 2012.

Kats, G., Alevantis, L. Berman, A., Mills, E. and Perlman, J. (2003). "The costs and financial benefits of Green Buildings." *Rep. Prepared for California's Sustainable Building Task Force*, Sacramento, CA.

Kibert, C.J. (2007). "The next generation of sustainable construction." *Building Research & Information*, 35(6), 595-601.

Kim, G., Park, C. S. and Yoon,K. P.(1997)."Identifying investment opportunities for advanced manufacturing systems with comparative-integrated performance measurement." *Int. J. of Production Economics*, 50 (1),23-33.

Korkmaz S., Riley, D., and Horman, M. (2007). "Effective indictors for high performance green building delivery." *Proc., ASCE-CIB Proc. of the 2007 Construction Research Congress*, ASCE, Reston,Va.

Korkmaz, S., Messner, J., Riley, D.R. and Magent, C. (2010a).”High performance green building design process modeling and integrated use of visualization tools.” *J. Archit. Eng.,* 16(1), 37-45.

Korkmaz, S., Riley, D.R., and Horman, M. (2010b). “Piloting evaluation metrics for sustainable high-performance building project delivery.” *J. Constr. Eng. Manage.*, 136(8), 877-885.

Koskela, L. (1992). Application of the new production philosophy to construction. *CIFE Technical Report,* No.72, Center for Integrated Facility Engineering, Dept. of Civil Engineering, Stanford University, Stanford, Calif.

Krueger, T., Page T., Hubacek, K., Smith, L. and Hiscock, K. (2012) “The role of expert opinion in environmental modeling.” *Environmental Modeling & Software*, 36(2012), 4-18.

Lai, I. K. W and Lam, F. K. (2010).“Perception of various performance criteria by stakeholders in the construction sector in Hong Kong.” *Constr. Manage. and Eco.*, 28(4), 377-391.

Lam, P. T. I., Chan, E. H. W., Chau, C. K., Poon, C. S. and Chun, K. P. (2009).”Integrating green specifications in construction and overcoming barriers in their use.” *J.Prof. Issues Eng. Educ. Pract.*, 135(4), 142-152.

Lapinsky, A. R., Horman, M. J. and Riley D. R. (2005). “Delivering sustainability: lean principles for green projects.” *ASCE Constr. Research Congress*, San Diego, CA, 27-31.

Lapinsky, A. R., Horman, M.J. and Riley D.R. (2006). “Lean processes for sustainable project delivery.” *J. Constr. Eng. Manage,* 132(10), 1083-1091.

Leicht, R. M., Hunter, S.T., Saluja,C. and Messner, J.I. (2010). “Implementing observational research methods to study team performance in construction management.” *J. Const. Eng. Manage.,* 136(1), 76-86.

Liker, J.K. and Meier, D. (2006). *The Toyota Way Field Book, a practical Guide for implementing Toyota’s 4Ps*. McGraw-Hill. New York, 17-37.

Lim, C. S., and Mohamed, M. Z. (1999). “Criteria of project success: An exploratory re-examination.” *In.t J. Project. Manage., 17*(4), 243-248.

Linstone, H. A., and Turoff, M. (Eds.). (1975). *The Delphi method: Techniques and applications.* Reading, MA: Addison-Wesley Publishing Company.

Magent, C., Riley, D. and Horman, M. (2005). High performance building design process model, *ASCE Construction Research Congress*, April 5-7, San Diego, CA, 424-428.

Mapp, C., Nobe, M.E.E. and Dunbar, B. (2011). “The Cost of LEED-an analysis of the construction costs of LEED and non-LEED banks”, *JOSRE,* 3(1), 254-273.

Markmann, C. Darkow,I.L. and von der Gracht, H. (2013). “A Delphi-based risk analysis – Identifying and assessing future challenges for supply chain security in a multi-stakeholder environment.” *Technological Forecasting & Social Change*, 80(9), 1815-1833.

Marphi. J. (2014). *Managing green building projects.* World Green Building Council Europe Regional Network. Presented for Turkish Green Building Council, March 10, 2014.

McGraw-Hill Construction (2006). *Green building smart market report: Design & construction intelligence,* New York.

Meryman, H. and Silman, R. (2004). “Sustainable engineering - Using specifications to make it happen.” *Struct. Eng. Int. (IABSE, Zurich, Switzerland),*14(3), 216-219.

Milani, A. S., Shanian, A. and Madoliat, R. (2005). “The effect of normalization norms in multiple attribute decision making models: A case study in gear material selection.” *Structural Multidisciplinary Optimization*, 29(4), 312-318.

Miles, M.B., Huberman, A.M. (1994), *Qualitative Data Analysis: An Expanded Sourcebook*, 2nd ed., Sage Publications, Thousand Oaks.

Mitchell, V.W. (1991). “The Delphi technique: An exposition and application.” *Tech. Anal. Strat. Manage.*, 3(4), 333-358.

Mogge, J. (2004). “Breaking through the 1st cost barriers of sustainable planning, design and construction.” PhD Diss., Georgia Institute of Technology, Atlanta, GA.

Molenaar,K. R., Sobin, N., and Anrillón, E. (2010). “A synthesis of best-value procurement practices for sustainable design-build projects in the public sector.” *J. Green Build.,* 5(4), 148-157.

Munro, R.A., Maio M.J., Nawaz, M.B. Ramu, G. and Zrymiak, D.J. (2008). *The certified six sigma green belt.* India, Dorling Kindersley Publishing Inc.

Nahmens, I. (2009). “From lean to green construction: a natural extension.” *Proc. of ASCE Construction Research Congress (CRC),*1058-1067.

National Charette Institute (NCI) (2007). “What is a charette?” < http://www.charretteinstitute.org/charrette.html > (accessed Jan. 24, 2014).

Nijkamp, P., Rietvelt, P. and Voogd, H. (1990). *Multi-criteria evaluation in physical planning' Amsterdam: North-Holland*. Elsevier Science Publishers B.V., Amsterdam, The Netherlands.

Nilson, M. L. (2005). “Quantifying the cost impacts of LEED-NC Gold Constuction in New York City.” Senior Honor Thesis. Department of Civil and Environmental Engineering, Lafayette College.

Ofori, G. and Kien, H. L. (2004). “Translating Singapore architects’ environmental awareness into decision making.” *Build. Res. Inf.*, 32(1), 27-37.

Okoli C. and Pawlowski, S.D. (2004). “The Delphi Method as a research tool: an example, design considerations and applications.” *Information & Management*, 42(1), 15-29.

Pan, W., Dainty A.R.J. and Gibb, A.G.F. (2012). “Establishing and weighting decision criteria for building system selection I housing construction.” *J. Constr. Eng. Manage.*, 138(11), 1239-1250.

Pearce, A. R. and Vanegas, J. A. (2002). “A parametric review of the built environment sustainability literature.“ *Int. J. Environ. Technol. Manage.*, 2(1-3), 54-93.

Porter, M. and van der Linde, *C.* (1995).*Green and competitive*. Harvard Business Review, 119-134.

Pulaski, M., Pohlman, T., Horman, M. and Riley, D.R. (2003). “Synergies between sustainable design and constructability at the Pentagon.” *Proc. of ASCE CRC,* 1-8.

Reed, W. and Gordon, E. (2000). “Integrated design and building process: Needed research and methodologies.” *Build. Res. Inf.*, 28/(5/6), 325-337.

Riley, D (2009). Personal Conversation Regarding Master’s Thesis Conclusion. Pennsylvania State University, Engineering Units. 2 April 2009.

Riley, D. R. and Horman, M. (2005). “Delivering green buildings: High performance processes for high performance projects.” *Proc., Engineering Sustainability 2005: Conf. of the Mascaro Sustainability Initiative.*

Riley, D. R., Magent, M. and Horman, M. (2004). “Sustainable metrics: a design process model for high performance buildings.” *Proc. CIB World Building Congress* Toronto, CA.

Riley, D. R., Pexton, K and Drilling, J. (2003). ”Procurement of sustainable construction services in the United States: the contractor’s role in green buildings.” *UNEP Industry and Environment*, April-Sep., 66-73.

Riley, D. R., Varadan, P. James, J.S., and Thomas, H.R. (2005). “Benefit-cost metrics for design coordination of mechanical, electrical, and plumbing systems in multistory buildings.”*J. Constr. Eng. Manage*., 131(8), 877-889.

Robichaud, L.B. and Anantatmula, V. (2011). “Greening project management practices for sustainable construction”. *J. of Manage. Eng.*, 27(1), 48-57.

Rowe, G. and Wright, G. (2001). “Expert opinions in forecasting: The role of the Delphi technique.” *Principles of Forecasting, International Series in Operations Research & Management Science*, 30 (2001), 125-144.

Rowe, G., Wright, G. and Bolger, F. (1991). “Delphi: A reevaluation of research and theory.” *Technological Forecasting and Social Change*, 39(3), 235-251.

Shih, H.-S., Shyur, H.-J. and Lee, E.S. (2007) “An extension of TOPSIS for group decision making”, *Math.and Comput. Modeling*, 45 (2007), 801-813.

Shrestha, P.P. and Pushpala, N. (2012). “Green and non-green school buildings: an empirical comparison of construction cost and sustainability.” *Proc. ASCE CRC*, 1820-1829.

Simonsson, P., Björnfot, A., Erikshammar, J. and Olofsson, T. (2012). “’Learning to see’ the effects of improved workflow in civil engineering projects.” *Lean Constr. J.*, 35-48.

Smith, A. (2003). “Building momentum: National trends and prospects for high performance green buildings.” *Rep. Prepared for the U.S. Senate Committee on Environment and Public Works*, USGBC, Washington, D.C.

Sprau, T. (2009) “Developing the Basis for Process Metrics for Sustainable Building Performance”. M.S. Thesis. Department of Architectural Engineering. The Pennsylvania State University.

Stegall, N. (2004). “Cost implications of LEED Silver Certification for new house residence at Carnegie Mellon University”. Senior Honors Research Project, Carnegie Inst. of Tech.

Swarup, L., Korkmaz, S. and Riley, D. (2011). “Project delivery metrics for sustainable, high performance buildings.” *J. Constr. Eng. Manage.*, 137(12), 1043-1051.

Syal, M.G., Mago, S. and Moody, D. (2007). “Impact of LEED-NC credits on contractors”. *J. Archit. Eng.*, 13(4), 174-179.

Tagaza, E. and Wilson, J.L. (2004). “Green buildings: drivers and barriers - lessons learned from five Melbourne developments.“ *Report Prepared for Building Commission by University of Melbourne and Business Outlook and Evaluation*.

TOKI, (2014). Toplu Konut Idaresi Baskanligi, <http://www.toki.gov.tr/english/3.asp> (accessed Sep. 15, 2014).

Triantaphyllou, E. (2000), “*Multi-Criteria Decision Making Methods: A Comparative Study”,* Kluwer Academic Publishers, The Netherlands.

Turner Construction Company (2012). “*Green building market barometer.”* <http://www.turnerconstruction.com/about-us/sustainability/green-market-barometer> (accessed Ap. 21, 2014).

USGBC (2009). U.S. Green Building Council. “LEED 2009 for New Construction and Major Renovations Rating System.” <http://www.usgbc.org/resources/list/study-guides >, (accessed Feb.10,2014).

USGBC (2014a). U.S. Green Building Council. < http://www.usgbc.org/projects/new-construction >, (accessed Dec. 10,2014).

USGBC (2014b). U.S. Green Building Council. < http://www.usgbc.org/articles/about-leed> , (published Oct. 17, 2014).

USGBC (2014c). U.S. Green Building Council. <http://www.usgbc.org/discoverleed/ certification/bd-c-new-construction/ > (accessed Feb. 5, 2015).

Vidal, L.A., Marle, F. and Bocquet, J.C. (2011). “Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects.” *Expert Systems with Applications,* vol.38, 5388-5405.

Weber, M. and Borcherding, K. (1993). “Behavioral influences on weight judgments in multi-attribute decision making.” *European Journal of Operational Research*, vol.67, 1-12.

Wiley, J.A., Benefield, J.D., and Johnson, K.H.(2010).”Green design and the market for commercial office space.” *Journal of Real Estate Finance and Economics,* 41(2), 228-243.

Williams K. and Dair C. (2007) “A framework of sustainable behaviors that can be enabled through the design of neighborhood-scale developments.” *Sustainable Development,* 15(3),160-173.

Womack, J.P. and Jones, D.T. (1996). *Lean Thinking: Banish waste and create wealth in your corporation*. Simon&Schuster: New York, NY.

Wu P. and Low S.P. (2010). “Project management and green buildings: lessons from rating systems.” *J. Prof. Issues Eng. Educ. Pract.,* 136(2), 64-70.

Wuellner, W.W. (1990).”Project performance evaluation checklist for consulting engineers.” *J. Manage. Eng.,* 6(3), 270-281.

Yin, R. K. (2003). *Case Study Research,* Sage Publications, 3rd ed., Thousand Oaks.

Yiu, C.Y. , Ho, H.K., Lo, S.M. and Hu, B.Q. (2005) “Performance evaluation for cost estimators by reliability interval method”, *J. Const. Eng. Manage.,*131(1), 108-116.

Yuan, J., Skibniewski, M.J., Li, Q. and Zheng, Lei (2010). “Performance objectives selection model in public-private partnership project based on the perspective of stakeholders”, *J. of Manage. Eng.*, 26(2), 89-104.

Yue, Z. (2011a). “An extended TOPSIS for determining weights of decision makers with interval numbers.” *Knowledge-Based Systems*, 24(1), 146-153.

Yue, Z. (2011b). “A method for group decision-making based on determining weights of decision makers using TOPSIS”, *Applied Mathematical Modeling*, 35(4), 1926-1936.

Yue, Z. (2012). “Extension of TOPSIS to determine weight of decision maker for group decision making problems with uncertain information”, *Experts Systems with Applications*, 39(7), 6343-6350.

Zanakis, S.H., Solomon, A., Wishart, N. and Dublish, S.(1998). “Multi-attribute decision making: A simulation comparison of select methods”, *European Journal of Operational Research,* 107(3), 507-529.

Zhang, X.L., Shen, L.Y., Wu, Y.Z. (2011). “Green strategy for gaining competitive advantage in housing development: a China study.” *J. of Cleaner Production*, 19(1), 157-167.