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IMPACT OF LEED® – NC PROJECTS ON CONSTRUCTORS
AND CONSTRUCTION MANAGEMENT PRACTICES

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IMPACT OF LEED®-NC PROJECTS ON CONSTRUCTORS AND CONSTRUCTION MANAGEMENT PRACTICES

By

Shilpi Mago

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ABSTRACT

IMPACT OF LEED®-NC PROJECTS ON CONSTRUCTORS
AND CONSTRUCTION MANAGEMENT PRACTICES

By

Shilpi Mago

As sustainable construction enters mainstream and the LEED®-NC green building rating system becomes synonymous with green buildings, the need to assess the impact of this rating system on constructors' practices is imperative. While owners and designers have played a prominent role in pursuing LEED® projects, there is a strong need to define the role of constructors' and their early involvement in the green building process. This research presents a comprehensive analysis of the impact of LEED®-NC credits on constructors and construction management practices. In addition, a database-query system was also developed as a tool to access these impacts by the constructors. Further, the research method used, was mapped to develop a process model for undertaking a similar impact assessment of green building programs on other construction sectors. The research outputs were developed with the help of four case study projects and an eighteen-member industry advisory group. These outputs would greatly assist constructors as they navigate LEED®-NC projects.

I dedicate this thesis to my family, for their love, support and trust in all my endeavors. Thank you, for being my Rock of Gibraltar, you all made it possible.

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INTRODUCTION

1.1 Overview

Sustainable development has long been recognized as the next step that humankind should take in order to recuperate from the aftermath of the industrial revolution (Gottfried 2000). Events such as the Stockholm Declaration, the Brundtland Report, and the Rio Summit have brought nations together to address humankind's increasingly negative impacts on the environment. According to some studies, construction industry is one of the largest contributors of these negative impacts (CICA 2002).

Within the broader perspective of sustainable development, the construction industry's effort to utilize natural resources efficiently and mitigate the harmful effects of buildings and construction activities on the environment is termed sustainable construction (Gottfried 2000, CICA 2002). Resource efficiency, in terms of green buildings, refers to high levels of energy and water efficiency, appropriate use of land resources, use of environmentally friendly materials, and minimization of life-cycle effects of building's design and operation on the environment (Kibert 2005). The need for sustainable construction has surfaced in the last 15 years, with a significant thrust in the last decade. One of the drivers behind this thrust is the realization of unprecedented energy consumption patterns of buildings (Mogge 2004). This realization has steered the interest of owners and designers towards sustainable design and construction practices. For instance, buildings in the United States consume one third of all primary energy produced and close to two thirds of electricity produced (Vanegas and Pearce 1997).

Globally, buildings are responsible for over 10% of the world's freshwater withdrawals, 25% of its wood harvest, and 40% of material and energy flows (Kibert 2005). In addition, the construction industry generates 8-20% of the total municipal solid waste (Fisk 2000, Augenbroe et. al 1998). According to Kibert (2005), 30% of all new and renovated buildings in the U.S. experience poor indoor environmental quality due to noxious emissions, off gassing from evaporation of harmful substances present in building materials, and pathogens resulting in low productivity which cause an annual loss of $60 billion. Thus, buildings have a significant negative impact on the environment and the health of their occupants.

Green buildings help to minimize this negative impact on the environment, and improve occupant health, by reducing or eliminating the air borne contaminants and improving the indoor air quality. In order to address the environmental impacts of buildings and construction activities, several researchers have suggested the inclusion of sustainability goals in construction project objectives (Houvila and Koskela 1998). This requires superimposition of sustainable concerns: minimization of environmental degradation, minimization of resource depletion, and creation of a healthy built environment, over the typical components of time, cost, quality, and safety as illustrated in Figure 1.1. Inclusion of sustainability as an integral goal in a construction project also brings forth the need to reconsider how the existing practices in the design and construction industry best align with this goal. In addition, the shift to incorporate sustainable practices into typical design and construction processes requires a redefinition of the existing role of project participants to effectively contribute in sustainable project objectives.

An important characteristic of sustainable projects is that they lend themselves to a multidisciplinary and integrated team effort rather than a typical linear design and construction process (Gottfried 2000). This integrated approach requires early involvement and greater participation of different project members in order to better utilize their technical expertise and knowledge.

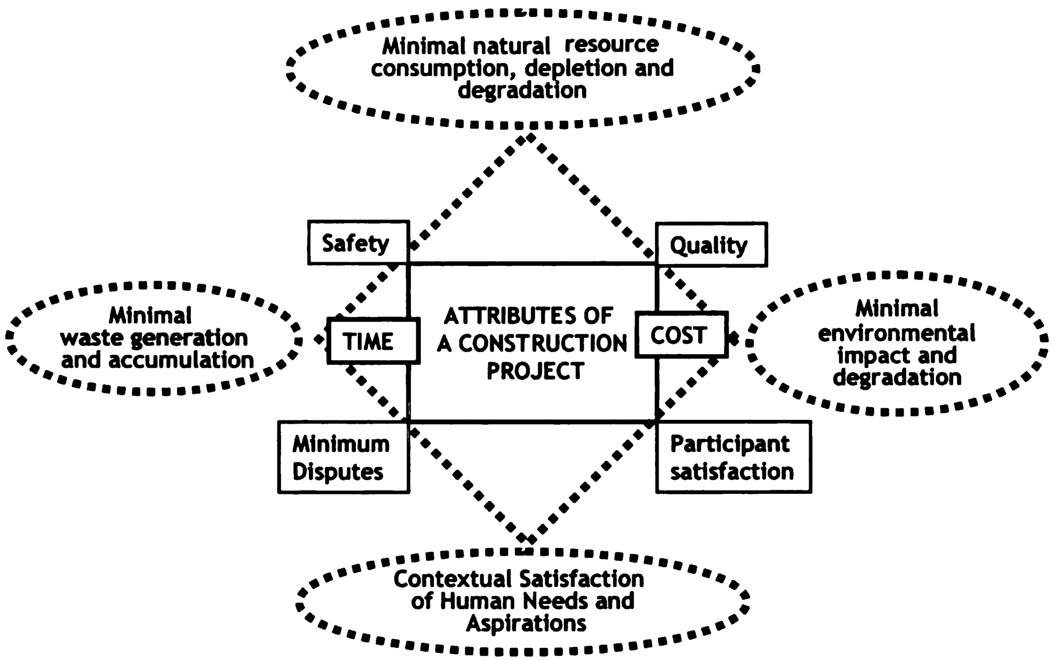


Figure 1.1: Incorporation of sustainability aspects in the traditional construction approach (modified from Houvila and Koskela 1998 and Syal 2006)

The green building movement in the United States has encouraged the creation of green building rating systems. The Leadership in Energy and Environmental Design (LEED®) Green Building Rating System, developed by United States Green Building

Council (USGBC) is one of the most widely accepted rating systems. The design and construction industry has gradually accepted the LEED® rating system in mainstream practice as evidenced through growth of LEED®-New Construction (NC) certified projects over the past few years (LEED 2005). The increase in LEED®-NC certified projects represents a steady and growing interest in green buildings. Mogge (2004) developed an evolution curve for green building design and construction under 5 phases of research, development, innovation, maturation and normative use as shown in Figure 1.2. This evolution curve is based on the assumption that growth in green building projects has doubled every year since 2000 and is continuing at this rate. With such a growth rate, the likely maturation time for the green building movement would occur around 2015; beyond which, green buildings will become normative practice. Based on this evolution curve, Mogge (2004) identified the current state of green building design and construction to be between development and innovation phases.

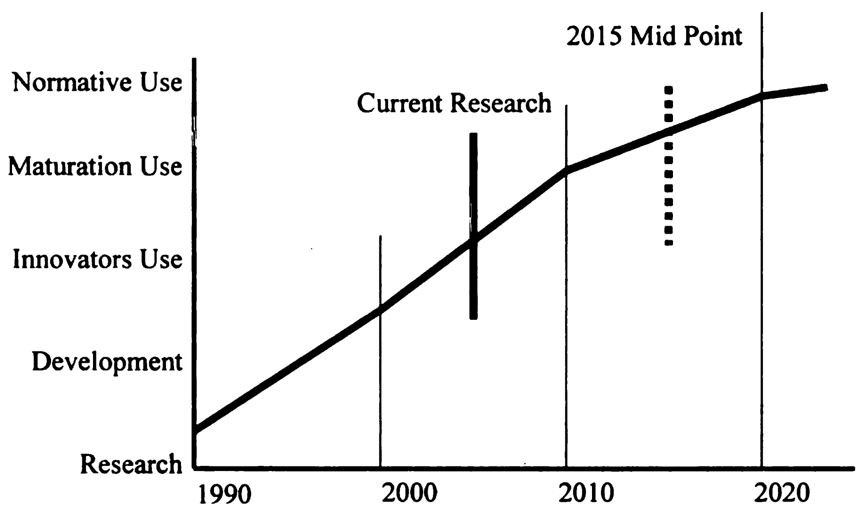


Figure 1.2: Likely Maturation Curve for Sustainable Buildings (Mogge 2004)

1.2 Research Need

The preceding sections focused on the growth of sustainable construction practices and green buildings in the last few years and the pivotal role of the LEED® green building rating system in this growth. Increase in LEED® certified buildings represents a growing demand for green buildings in the design and the construction industry. In the green building movement, the constructors were initially slow in becoming a part of this movement (Riley et. al. 2004, Syal 2005, GVRD 2004). This is undergoing a change, however, and constructors are making the effort to become a part of this initiative. The following sections discuss the research intent with focus on need for green buildings, the green building rating tools with focus on LEED®-NC and a constructor's role in the green building movement.

1.2.1 Need for Green Buildings

The green building movement accelerated after the 1970's energy crisis. In the early 90s, with growth in environmental concerns about issues such as ozone depletion, global climate change, and dependence on fossil fuels, the interest in green buildings received great attention (Kibert 2005). Moreover, the impact of buildings on the environment indicates the short-term planning efforts, which fail to take into account the lifecycle performance of buildings. A gradual shift towards an efficient utilization of natural resources is beginning to appear, however, evident from the construction sector's effort in pursuit of sustainability (CICA 2002). This shift is also an acknowledgement of benefits related to green building design and construction practices. Various cost studies have attempted to quantify these benefits in terms of cost savings and have proved instrumental in encouraging owners to pursue green projects. In addition, designers and owners are readily recognizing the benefits of green buildings such as healthier workplaces, reduction in life cycle costs, increased asset values, and reduced energy consumption (Needy et. al. 2004).

The cost studies have identified increases in worker productivity and savings in operational cost due to decreased energy consumption as two primary benefits of green buildings. As shown in Table 1.1. Kats et al. (2003) concluded that for a typical green office building, the monetary benefit incurred over 20 years will be in the range of $ 49.85 - $ 66.25 per sq. ft. The study included savings due to energy, lower emissions, water, operations and maintenance, and productivity and health benefits, while the extra cost of making the building green was deducted from the savings.

Table 1.1: Financial Benefits of Green Buildings, Cost per sq. ft. (Kats 2003)

Category	**20-year Net Present**
Energy Savings	$ 5.79
Emission Savings	$ 1.18
Water Savings	$ 0.51
Operations and Maintenance	$ 8.47
Productivity and Health benefits	$ 36.90 - $ 55.30
Subtotal	**$ 52.85 - $ 71.30**
Green Cost Premium	(-$ 3.00 to -$ 5.00)
Total 20- year benefit	**$ 49.85 - $ 66.25**

Kats et al. (2003) also concluded that the employee costs in a typical commercial building are approximately 89 percent of the total building costs and increases in worker productivity have a significant impact on the owner's savings. The study also stated that an increase in worker productivity of 1 percent translates to an annual savings of $600 -

$700 per employee, or $3/sq.ft. of the area. Moreover, the overall cost savings from green buildings vary from $49.85 to $66.25 per square foot, which is over 10 times the additional cost associated with green buildings. In addition, maintenance and energy savings are other sections of potential cost savings in green buildings. Similarly, Green Building Alliance (GBA) conducted a study in 2003 on productivity benefits observed by Herman Miller, a furniture manufacturer, in their new green office building. The green office building accrued savings worth $6 million over a lease of 7 years, with a breakdown of 33% in building costs, 41% in operating costs, and 66% in churn-related costs (GBA 2003).

These studies have given a definitive push towards recognition of green building benefits, by owners and designers, which is evident in the increasing number of green buildings. Concurrent with the acceptance of green buildings has been the emergence of green building rating systems, which exist to quantify the extent of sustainable/ green features incorporated in these buildings. The next section focuses on green building rating tools available and discusses in detail the LEED® Green Building Rating System.

1.2.2 Green Building Rating Tools - LEED®-NC Green Building Rating System

With growth in green buildings, has emerged the need to measure and assess their performance, with the help of green building rating systems. These rating systems serve two functions; of promoting high performance buildings, and creating the demand for sustainable construction (USGBC 2006). One of the most significant indicators of the shift towards green design and construction practices in the past few years is the growing number of LEED®-NC certified buildings in the United States (USGBC 2006).

There are other green building assessment systems used worldwide, such as Building Research Establishment's Environmental Assessment Method (BREEAM), Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), Green Globes™ US, and Green Building (GB) Tool. BREEAM, a primary system used in the United Kingdom, was one of the first sustainable building assessment tools used worldwide. The Japanese Sustainable Building Consortium developed Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in 1990, primarily for application to the Japanese construction industry (Kibert 2005, Fowler and Rauch 2006). Green Globes US, is an assessment tool developed by the Green Building Initiative and used in the United States, Canada and the United Kingdom. It is an online tool and consists of questionnaires that help the project team in assessing the building systems and practices used in the project. GBTool software was developed in Canada, as a part of an international effort by the Green Building Challenge. The GBTool software assesses the estimated performance of a building (GBTool 2007).

The LEED® rating system is widely accepted in United States and is being introduced in countries such as China, India, and Canada (LEED 2005). The eminence of the LEED® rating system is evident in its growth over the years, since 1998. As of November 2006, there are 623 LEED®-NC certified projects and 4,617 LEED®-NC registered projects. In addition, the annual market for green building products and services has grown to $7 billion in 2006 and the number of buildings aiming for LEED® certification has consistently increased in the last 9 years (Kibert 2005 and USGBC 2006).

Moreover, these increasing numbers signify the owners' demand to pursue sustainable buildings and achieve LEED® certification. According to USGBC, federal, state, and local governments own 46 percent of LEED® certified projects and 56 local governments have adopted the LEED® rating system into their building standards (USGBC 2006). The General Services Administration (GSA) submitted a report to the Chairman of Transportation, Treasury, Housing and Urban Development, in September 2006, stating that "...the U.S Green Building Council's LEED®-NC rating system continues to be the most appropriate and credible sustainable building rating system available for evaluation of GSA projects" (Fowler and Rauch 2006). Kibert (2005) presented a hypothesis, that if close to 1% of all commercial and institutional buildings were designed according to LEED® standards in 2003, and with an expected increase every year, by 2008 the majority of buildings in the United States may be LEED® certified and the LEED® rating system may become an industry standard in the coming years.

1.2.3 Role of Constructors in the Green Building Movement

Owners, both public and private, along with designers are taking the lead in pursuing sustainable design and construction practices. The designers have been a dominant part of the green building movement since the very beginning, as they are the creators of the initial idea for the built environment (Riley et. al. 2003). As both the source (designer) and the end user (owner) are readily adopting sustainable design practices, however, it becomes imperative for the process implementer (constructor) to become an active team member in successfully implementing green building projects

(Syal 2005). A constructor can provide input on aspects such as material selection, system performance, decreasing construction waste, and improving indoor air quality. In addition, the constructor can also provide input on streamlining construction methods, value engineering methods, and constructability reviews in order to achieve the green project goals. There is a need to define a broader role of constructors and their early involvement in the green building process (Riley et. al. 2003, Mogge 2004, Samaras 2004). As the LEED rating system makes inroads into the mainstream design and construction industry, the constructors need to contribute towards a project's green objectives by understanding LEED and their role in executing green buildings, through early involvement and greater participation during the major project phases (Syal 2005). The key here is to move from the traditional linear construction process to a more integrated, cyclic system.

The incorporation of a constructor as an integral team member in a green building process comprehends the concept of sustainable development in the true sense as it imbibes an integrated design and construction approach (Samaras 2004). Early collaboration of design and construction teams, in a green building project, help to streamline and optimize the design and construction process by sharing knowledge between cross-functional teams (Houvila and Koskela 1998). Through their early involvement in a project, the construction teams can provide technical expertise to streamline the design and construction process of green buildings (Riley et. al. 2004, Pulaski et. al. 2003). Moreover, as Samaras (2004) states that with greater momentum in the sustainability movement in the construction industry, the need to design and construct in harmony with the environment will not be an isolated component, but instead become part of common practice. With improvement in technology, the learning curve of sustainable construction practices for constructors will tend to stabilize in aspects such as increased efficiency of building systems, procurement and supply chain operations, material and resource recovery methods, and life-cycle asset values.

The above noted discussion underscores the growth of green buildings and the resultant acceptance of the LEED®-NC rating system by owners and designers. As an essential part of a project team, the constructors can be a vital source of input in successfully executing green buildings. This momentum of the green building movement reinforces the need and timeliness for this research that attempts to identify the impact of green buildings on a constructor's role with the LEED®-NC Rating System as a reference.

1.3 Research Goal and Objectives

The overall goal of this research is to analyze the role of constructors in LEED® projects. This goal was achieved by analyzing the impacts of these projects on constructors' activities and construction management practices. The following objectives were accomplished to achieve the research goal.

1. *Identify and analyze the impact of LEED®-NC requirements on constructors and construction management practices.*

   Step 1: Familiarize with LEED® - NC V 2.2 and review existing literature to understand and assimilate the current research in sustainable design and construction.

Step 2: Develop the Project Phase Impact Matrix to map a constructor's role in green buildings during various project phases.

Step 3: Conduct case studies through site visits and industry input.

Step 4: Develop the LEED® - NC Credit Impact Matrix to map the impact of LEED®-NC credits on constructor's activities/ practices.

Step 5: Based on a constructor's role in different project delivery methods, identify responsibilities in a LEED® project.

Step 6: Conduct an Industry Advisory Group (IAG) work session to obtain feedback on the outputs developed in steps 4 and 5.

2. *Develop the database-query system to assist the constructors in successfully navigating LEED® - NC rating system.*

   Step 7: Review literature on database systems to understand their architecture and working mechanism.

   Step 8: Identify the entities (tables, forms and queries) required for developing the database, create the entity relationship diagram, and develop the rules of data retrieval, based on the LEED® - NC Credit Impact Matrix.

   Step 9: Develop the database, based on information synthesized in objective 1.

   Step 10: Obtain feedback from the IAG.

3. *Based on the methodology followed in this research, develop a process model for investigating a constructor's role in other green buildings programs such as LEED-Homes, LEED – Commercial Interiors, etc.*

Step – 11: Compile the comprehensive methodology steps, followed in objectives 1 and 2.

Step – 12: Develop a process model to assess the impact of a green building program on a constructor's activities.

Step – 13: Illustrate the application of the process model.

1.4 Research Scope and Limitations

1. The focus of this research is on LEED®-NC certified or registered commercial buildings.
2. In this research, the term constructor refers to General Contractors and Construction Managers.
3. One case study project is used in detail due to availability of data from construction professionals and owners wishing to share project information and ease of accessibility. Other case study projects are used to a varied extent due to their location, stages of these projects and availability of data. Information from these projects was solicited by the members of the Industry Advisory Group.
4. This research uses the terms "sustainable" and "green" synonymously and interchangeably.
5. Project specific characteristics such as size, type and level of LEED®-NC rating may result in varied impact on constructors' activities.
6. A formal interview process was not used for this research. Instead the interviews were held as informal and open ended discussions.

1.5 Research Methodology

The last section provided an overview of the research methodology as it relates to the objectives and the work steps undertaken to achieve them. These steps are discussed in detail in the following sections and Figure 1.3 illustrates the research methodology graphically.

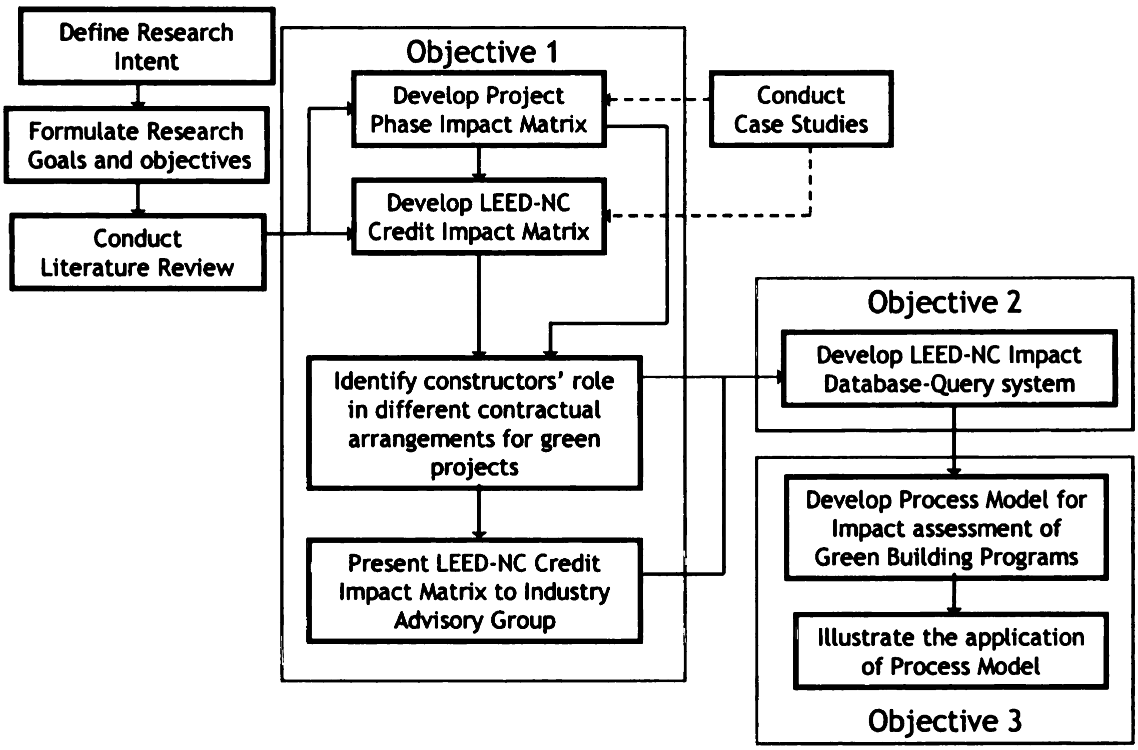


Figure 1.3: Research Methodology

1.5.1 Objective – 1

Identify and analyze the impact of LEED® - NC requirements on construction management practices.

Step 1: Familiarize with LEED® - NC V 2.2 and review existing literature to understand and assimilate the current research in sustainable design and construction.

The first step of this research entailed developing a detailed understanding of the LEED® - NC V2.2 rating system, as it was imperative to understand the intents and strategies of LEED® - NC credits to identify possible responsibilities of a constructor in a green building process. For instance, some of the credits that require a constructor's significant involvement in a green building process were identified in this step, such as the intent of Energy and Atmosphere (EA) and Material Resources (MR) category, which by virtue of their requirements, reveal significant opportunities to involve constructors.

The literature review covered the following categories:

Category 1-A: Sustainable Design and Construction

- Attributes of green buildings
- Green building rating system
  - LEED®-NC green building rating system
  - Green Globes

Category 1-B: Constructor's Role in Green Buildings

- Construction management aspects of green buildings
- Cost aspects of green buildings

Category 2: Database / Query systems, Process-Modeling tools

Two main categories of literature were reviewed for this research. Category 1 is comprised of two sub categories; category 1A- sustainable design and construction and category 1-B- constructor's role in a green building process. Both these sub categories have further divisions as mentioned in the beginning of this section. The second category focuses on the database/query systems and process models. Category 1 assisted in achieving the first research objective, while Category 2 provided the necessary background to achieve the second and third research objective.

Category 1-A focused on green building attributes and green building rating systems. The first section of Category 1-A includes a review of green building attributes, namely; energy efficiency and renewable energy, land and water resources, resource conservation and recycling, and indoor environmental quality (Vanegas and Pearce 1997, Augenbroe et. al. 1997, Kibert 2005). These attributes form the five categories of LEED - NC rating system and are discussed in Chapter 3. The second section of Category 1-A discusses green building rating systems, with focus on the LEED® - NC green building rating system, and a short discussion on Green Globes as the other rating system used in the United States. Category I-B reviewed the constructor's role in green buildings, in relation with construction management and cost aspects of green buildings. This section discusses the opportunities in a green building process, in which a constructor can make a significant contribution. It also highlights the importance of a constructor's involvement in optimizing and streamlining the green building process and offsetting the high initial cost associated with green buildings. The construction management aspect of green buildings discusses existing and ongoing research, which aligns with some of the assertions put forward by this research. One such initiative is being pursued at Penn State University, with focus on improving the delivery process of green buildings. This research initiative has identified different aspects, methods, and means of how green building project delivery system can enhance the sustainability pursuits of a project.

Step 2: Develop the Project Phase Impact Matrix to map a constructor's role in green buildings during various project phases.

Based on the literature reviewed in step 1, the Project Phase Impact Matrix was developed. This matrix consists of constructors' responsibilities in a LEED® - NC project, categorized under different project phases. The Project Phase Impact Matrix is the synthesis of the literature reviewed in the form of a preliminary analysis of this research. The Project Phase Impact Matrix identified a constructor's contribution in achieving LEED® - NC credits, during different project phases. It formed the basis for the LEED® - NC Credit Impact Matrix as the Construction Management (CM) functions, used to develop the structure of the LEED® - NC Credit Impact Matrix were identified from the Project Phase Impact Matrix and assisted in developing the structure for conducting case studies.

Step 3: Conduct case studies through site visits and industry input.

In this step, four case study projects were studied. These case studies were reviewed under the research initiative at Michigan State University, supported by the William A. Klinger Memorial Research Award, AGC Education and Research Foundation and the Environment Research Initiative (ERI), Michigan State University. The researcher acknowledges the funding for this project from the William A. Klinger Memorial Research Award, AGC Education and Research Foundation and the Environment Research Initiative, Michigan State University. In addition, the valuable role of the industry advisory group and the project teams of the four case study projects is gratefully acknowledged. As this research was conducted under this research initiative, the same case study projects were used and all projects had the following characteristics:

- The projects are commercial buildings that are either LEED® certified or registered for certification.
- The project team was willing to share project information.
- The focus group in the case study project teams consisted of – estimators, cost engineers, project engineers / superintendents, project managers, facility managers and LEED® coordinators (from constructors team).

An industry advisory group (IAG) was formed, comprised of design and construction personnel. The role of IAG was significant in providing an industry perspective to the research findings and their experience with LEED® projects through examples and lessons learned.

The case studies were conducted as informal discussions with the project planning and execution team (constructor's team). The informal discussion facilitated sharing of lessons learned by the construction team. The CM functions identified from the project phase impact matrix were used as a format to collect information from the case study projects. This information was analyzed and incorporated in the LEED®-NC Credit Impact Matrix. A detailed discussion of the case study selection process is presented in Chapter 3.

Step 4: Develop the LEED –NC Credit Impact Matrix to map the impact of LEED®-NC credits on constructor's activities/ practices.

After conducting the case studies, the LEED®-NC Credit Impact Matrix was developed. This matrix was developed from three sources; the Project Phase Impact matrix, case study data and analysis, and the literature reviewed. The intention of developing this matrix was to address the impact of all LEED®-NC credits on the constructor's processes. The organization of this matrix consists of two components; LEED®-NC categories and credits and CM functions identified from the Project Phase Impact Matrix. In the LEED®-NC Credit Impact Matrix, the impact of each credit was identified on six CM functions as constructor's responsibilities. In Chapter 3, a detailed discussion of the development of this matrix and an example is presented.

Step 5: Based on a constructor's role in different project delivery methods, identify responsibilities in a LEED® *project.*

In this step, a constructor's role in green building projects was identified for different project delivery methods. These contractual relationship maps were developed from the literature reviewed and the impacts identified in the LEED®-NC credit impact matrix.

Step 6: Conduct an Industry Advisory Group (IAG) work session, to obtain feedback on the outputs developed in steps 4 and 5.

In this step, the LEED®-NC Credit Impact Matrix was presented to the IAG. The IAG members provided input and feedback in the form of examples based on their experience and the current industry practices in green buildings, which was incorporated in the matrix. Due to the diversity in the composition of IAG, members from the design and construction industry contributed their knowledge, which rendered the feedback coherent. Details of the IAG are included in Chapter 3 and excerpts from the comments received on the matrix are included in Appendix E.

1.5.2 Objective – 2

Develop the database-query system application to assist the constructors in navigating the LEED®-NC rating system and successfully executing LEED® projects.

Step – 7: Conduct literature review of database systems to understand their architecture and working mechanism.

In this step, literature pertaining to database - query systems was reviewed. The intention of this step was to understand the construct, working mechanism, architecture, and the components required to create database - query systems.

Step – 8: Identify the entities (tables, forms and queries) required to develop the database, to create the entity relationship diagram, and to develop the rules of data retrieval, based on the LEED®-NC Credit Impact Matrix.

This step involved the identification of type of database to be developed, database entities such as tables, forms and queries required, and the relationship between these database entities. In addition, from the LEED®-NC Credit Impact Matrix, three components namely; i) LEED®-NC categories and credits, ii) CM functions, and iii) the impacts identified were included in the database. Based on the LEED®-NC Credit Impact Matrix, the queries required for sorting and retrieving the impacts were formulated. The database design was based on its potential users from the construction team, such as project managers, estimators, field engineers, and the CM functions helped in categorizing the impacts for easy access.

Step – 9: Present the database to Industry Advisory Group and obtain feedback and input.

After developing the database, it was presented to the IAG for input and feedback on aspects such as user interface and ease of accessing the information.

1.5.3 Objective – 3

Based on the methodology followed in this research, develop a process model for similar research for investigating a constructor's role in other green buildings programs, such as LEED®- H, CI, etc.

Step – 10: Compile the comprehensive methodology steps, based on objectives one and two.

In this step, the detailed research methodology steps for objective 1 and 2 were compiled to map the broad phases for assessing the impact of LEED®-NC projects on construction management practices.

Step – 11: Develop a typical process model for assessing the impact of a green building program on constructors' activities.

Based on the process map developed above, a process model was developed to identify a constructor's role in implementing a green project for other sustainability programs. In the process model developed, detailed process tasks were outlined.

Step – 12: Illustrate the application of the green building program Impact Assessment on constructors' activities process model.

This step was comprised of illustrating the application of the process model. For this illustration, LEED®- Homes (LEED®-H) was taken as the reference green building rating system and the impact was assessed on a homebuilder's role in compliance with this rating system.

1.6 Deliverables/ Research Contribution

This research attempts to identify the impact of LEED®-NC projects on construction management practices with focus on a constructor's role in a green building process. The following research deliverables were developed and are discussed in the subsequent chapters:

- Documentation of the constructor's responsibilities in a LEED®-NC project for different project phases.
- Documentation of constructor's role in achieving the LEED®-NC credits.
- Development of a database/query system that defines the constructor's responsibilities, based on LEED®-NC requirements, for the five CM functions identified in this research.

- Development of a detailed process model to identify the impact of other green building rating systems on the constructor's activities, which could be employed by other researchers.

1.7 Summary

In the wake of sustainable construction entering mainstream practice, and the LEED®-NC green building rating system becoming synonymous with green buildings, the need to assess the impact of this system on the constructor's practices is imperative. This underscores the research intent, which attempts to analyze a constructor's role in implementing LEED®-NC projects. This chapter provides an overview of the research goals, objectives, intent, and a detailed discussion of the research methodology used.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The literature reviewed for this research builds from two main categories, and the first category is further divided into two sub categories. Category 1 establishes the existing knowledge of sustainable design and construction, with focus on the constructors' role in green buildings. Category 2 focuses on the database/query-based systems and process modeling concepts. The breakdown of the focus areas of each literature category is shown in Figure 2.1.

Category 1-A : Sustainable Design and Construction
▪ Green Building Attributes ▪ Green Building Rating Systems ➢ LEED®-NC Green Building Rating System ➢ Green Globes
Category 1-B : Constructor's Role in Green Building Process
▪ Construction Management Aspects of Green Buildings ▪ Cost Aspects of Green Buildings
Category 2 : Database/Query Systems and Process Models

Figure 2.1: Literature Categories Reviewed

The existing body of literature pertaining to green buildings can be broadly categorized under three main categories: green building attributes, cost impacts of green buildings, benefits of green buildings and the green building rating systems. As this research centers on the constructor's role in LEED®-NC projects, it was imperative to gain an understanding of this rating system and the attributes of green buildings. The constructor's role in green buildings is discussed under two sub categories of construction management and cost aspects of green buildings. The second category of the literature reviewed deals with database/ query-based and process modeling systems that assisted in the design of the database/ query-based tool for constructors to effectively contribute in LEED® projects.

2.2 Sustainable Design and Construction

Sustainable construction represents the efforts of the construction industry in reducing the dependence of the built environment on natural resources and identifying opportunities, strategies and technologies to contribute towards sustainable development (Kibert 2005, Vanegas and Pearce 1997). As Samaras (2004) notes, the construction industry is a major participant in the sustainability movement as it is the foremost contributor to detrimental impacts on the environment. According to Kibert (2005), in the United States production and manufacturing of building components, and the construction activities themselves, consume more than 6 billion tons of basic materials annually. In addition, construction activities generate staggering quantities of waste with a very small fraction of the waste being recycled or reused. Annually, 145 million tons of construction and demolition waste is generated in the United States, out of which 92 percent is from demolition activities and the rest from construction activities (Augenbroe et al. 1998, Kibert 2005). Moreover, buildings consume 30% of total energy and 60% of electricity produced in the United States, and they are responsible for producing 25% of carbon emissions in the country (Augenbroe et al. 1998).

In response to these harmful impacts, the construction industry has been gradually steering towards efficient utilization of natural resources. Concurrently, there has also been an increase in green building rating tools to measure this resource efficiency. In the United States, LEED®-NC green building rating system, developed by USGBC is a widely accepted system.

2.2.1 Attributes of Green Buildings

From the inception of the green building movement, several drivers have been identified to characterize green buildings (Gottfried 2000, Kibert 2005, Augenbroe et al. 1998). These attributes also form the core of the LEED®-NC rating system. This section presents a discussion of these attributes and their relationship with LEED®-NC rating system.

2.2.1.1 Energy Efficiency and Renewable Energy

Energy conservation has been one of the central themes of sustainable construction efforts. The environmental impacts of extracting and using non-renewable energy sources are profound, and the cost of extracting energy from such sources is ever increasing. Green buildings employ methods, systems, and technologies to reduce the energy consumption in terms of lighting and HVAC and R equipments over the life of the building (Gottfried 2005). Energy in some form or the other is one of the necessities for human kind to survive. The energy crisis of the 1970's depicted the dependence of human kind on energy sources and the need to conserve these sources for its survival. Energy consumption in buildings constitutes an entire gamut of issues, such as building envelope design, use and design of fenestrations, size and design of mechanical and lighting systems and equipments, use of passive and renewable energy systems, use of roofing materials, etc.

The LEED®-NC 2.2 covers most of these aspects of energy conservation in its third category of Energy and Atmosphere. It also includes additional impacts of energy systems on the environment, such as the impact of refrigerants used in the building systems on the ozone layer and use of renewable energy sources (LEED 2005).

2.2.1.2 Land and Water Resources

Another tenet of green buildings is the efficient use of land and water resources. This includes site selection, location of the building on the project site, relationship of the building with the local ecosystems and careful coordination of the site's geology, topography, hydrology, wind patterns, solar movement, and existing natural habitats (Kibert 2005). This includes the urban development aspects, which aim at steering development into areas with existing facilities and infrastructure, such as increasing access to mass transit and reducing dependency on automobiles to address the rapid urbanization of green fields (Gottfried 2000). Water consumption also ties in closely with project sites and building use. Water is an important element required for survival of humans and other species. With buildings using 12% of fresh water withdrawals in the

United States, their impact on high quality potable water is evident (Kibert 2005). Green buildings stress reducing the consumption of potable water and reusing wastewater in order to extend the supply of freshwater, maintain balance in ecological systems, and improve human health (Augenbroe et al. 1998). This includes use of alternative water sources for irrigation and waste disposal in buildings, such as rainwater, reclaimed water, and gray water. The LEED®-NC categories of Sustainable Sites and Water Efficiency address these concerns.

2.2.1.3 Resource Conservation and Recycling

A third major attribute of green buildings is resource conservation and recycling. Construction waste accounts for more than one fourth of waste sent to landfills (Kibert 2005). Green buildings work in closed material loops in which, at the end of the useful life of the resources, they are either used as a new resource in another system or reused in the existing system. These loops are defined by four characteristics; i) reuse of existing structures and building components; ii) reduction in material use; iii) use of materials obtained from renewable resources; and iv) use of recyclable and recycled content materials (Gottfried 2000). All these characteristics aim to achieve the basic objective of reducing waste and using existing natural resources efficiently, which is the intention of the LEED®-NC category of Materials and Resources (MR).

2.2.1.4 Indoor Environmental Quality

The impact of indoor environmental quality on human health has been investigated due to the potential liability a design and construction team may have regarding occupant health. According to Kibert (2005), in the United States, \$140 billion are spent annually in direct medical costs due to indoor air quality problems. Moreover, as energy efficient buildings have more airtight envelopes, the potential risk of indoor air quality problems is higher. Pollutants such as material off gassing (chemical, biological, and particulate matter), humidity, odor, lighting quality, temperature, and noise affect the indoor environmental quality of buildings (Gottfried 2000). The source of these pollutants is a combination of building design, construction, and occupant activities. Green buildings attempt to curb these three sources by ensuring source, ventilation, occupant activity, and building maintenance control (Augenbroe 1998). LEED®-NC category of Indoor Environmental Quality, with emphasis on materials with low Volatile Organic Compounds (VOC), Indoor Air Quality (IAQ) management during construction and post construction, and use of day lighting as an essential building characteristic, attempts to eliminate these sources of pollutants.

The attributes discussed above are not exhaustive but are some of the characteristics of green buildings that are addressed in the LEED®-NC rating system. Chapter 3 discusses in detail the impact of LEED®-NC credit requirements on the constructor's activities.

2.2.2 Green Building Rating Systems

The green building attributes discussed above are incorporated in projects and their performance is assessed, based on the criteria defined by green building rating systems. A brief discussion in Chapter 1 described various green building rating systems used around the world. As this research builds on the LEED®-NC rating system, this section focuses on the requirements of LEED®-NC. In addition, it will also discuss Green Globes, which is another green building rating system used in the United States.

2.2.2.1 LEED – NC Green Building Rating System (LEED 2005)

United States Green Building Council (USGBC) introduced the LEED®-NC rating system in 1998. USGBC sought to bring together a comprehensive initiative for addressing the impacts of buildings within the environmental, social, and economic context (LEED 2005). The LEED®-NC green building rating system is a third party certification system, which allows owners and developers to voluntarily achieve a consensus rating based on four levels; certified with 26 -32 points; silver with 33 – 38 points; gold with 39 – 51 points and platinum with 52 - 69 (LEED 2005). LEED®-NC focuses on new commercial construction and major renovation projects. The rating is based on a set of performance-based standards under the six categories of Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality and Innovation and Design Process. Under LEED® certification, points are awarded for each of these categories that address specific environmental building related impacts, based on a whole building performance approach (LEED 2005). More details of LEED®-NC rating system as it relates to the proposed research are discussed in Chapter 3.

2.2.2.2 Green Globes

Under the leadership of Green Building Initiative (GBI), Green Globes, a web-based green management tool, was developed in 1996 and introduced in the United States in 2004. It includes an assessment protocol, a rating system, and a guide for integrating environmentally friendly design into buildings. It consists of modules for New Construction and Continual Improvement of Existing Buildings based on third-party verification. The assessment system is based on different questionnaires for each project phase, which guides the project teams to incorporate various sustainability features throughout the design and construction phases of the building. The rating consists of four categories based on the score achieved, ranging from 35% to 100%. In 2005, GBI became the first green building organization, which was accredited as a standards developer by the American National Standards Institute (ANSI) for developing the Green Globes Rating system.

2.3 Constructor's Role in Green Building Projects

This section presents the constructor's role in the green building process. The central theme of this research is to understand the impact of LEED®-NC projects on construction project management practices and define a constructor's role in a green building process. In order to define this role, it is imperative to understand the significant drivers in a green building process, and identify potential opportunities of a constructor's contribution in achieving these attributes. Existing literature of constructor's contribution in green buildings is fragmented and diverse. In order to assimilate the literature, the researcher has created two categories, namely i) Construction Management Aspects of Green Buildings and ii) Cost Aspects of Green Buildings. These categories are discussed in the subsequent sections.

2.3.1 Construction Management Aspects of Green Buildings

As owners realize the benefits of green buildings and the demand for such projects increases, a strong need emerges to rethink the delivery process of these buildings. This is required as high performance green buildings impose new challenges on the typical design and construction processes (Horman et al. 2006, Pulaski et al. 2005). These new challenges transpire as greater responsibility for design decisions, planning, management, and execution of construction operations for different project participants. Some of the direct contributions of a constructor in a green building process are estimating and waste recycling (Riley et. al 2003). A constructor's contribution, however, extends beyond these basic activities and covers some of the significant characteristics of green building delivery process. In addition, one of the major concerns in green buildings is the cost implications which, as already mentioned, are a function of several green building characteristics discussed below.

Existing and ongoing research identifies several characteristics of the delivery process of green buildings (Horman et al. 2006, Riley et al. 2003, Syphers et al. 2003, Kibert 2005, Pulaski et al. 2003, and Pulaski et al. 2006). The researcher has presented a discussion of a constructor's contribution in each of these characteristics, based on existing research. The characteristics identified include,

- Establish an integrated project team
- Explore the contribution of constructability reviews and value engineering concepts to improve green building construction processes
- Identify synergies between green building methods and other construction practices, such as lean construction

- Focus on whole building approach to efficiently utilize natural resources
- Establish clear goal for a green project
- Educate different participants in a green building project team
- Use contractual methods to augment greater participation of project members.
- Emphasize aspects of commissioning and energy modeling in LEED® projects to offset upfront costs

As observed by Pulaski et al. (2003) an integrated design and construction team provided applied knowledge of construction methods and materials, while giving pertinent cost information, in the case study of Pentagon renovation. The authors cite the instance of early involvement of the mechanical contractor in the design process that led to streamlined installation of the mechanical system, smaller equipment size, less ductwork and more options for admitting greater daylight in the interior spaces. Similarly, Horman et al. (2006) affirmed that successful execution of a high performance building is contingent on successful planning and coordination of the project team. The author states that it becomes critical to have greater involvement of design and construction teams, particularly the constructor early in the design process of such projects. Moreover, in order to have a stronger dedication towards the green project goals, the integration should extend through the constructor's team to the subcontractors, equipment and product manufacturers, vendors, and suppliers (Pulaski et al. 2006).

Pulaski et al. (2003) identified constructability reviews and green value engineering as some of the significant contributions of a construction team in achieving the sustainable objectives of a project. Both sustainable design and constructability reviews achieve efficient resource utilization and reduce inefficiency, which ties these two initiatives together (Pulaski et al. 2005). As these attributes are addressed separately in green building projects, however, the combined results are not reaped (Houvila and Koskela, 1998, Lapinski et al. 2006). Moreover, the constructability aspects in a sustainable building project are essential as they require expertise and involve immense pre-construction planning on part of the constructor (Riley et al. 2003, Mogge 2004). This requires a redefinition of the constructor's role and intervention in both design and project planning phases, for successful implementation of sustainable building projects. Moreover, as green buildings involve complex designs and integrated building systems, a constructor's understanding of these complexities is imperative. For instance, use of more reflective paint can improve the efficiency of an indirect lighting system and allow reductions in the size of electrical and cooling systems (Riley et al. 2003).

The third characteristic observed in the delivery process of green buildings is the application of lean construction principles. Lean construction principles closely tie in with the goals of sustainable building design, wherein the process becomes equally important as the product and efficiency is achieved by minimizing resource consumption and eliminating the waste. (Pulaski et al. 2005, Houvila and Koskela, 1998). Both lean principles and green construction find common ground in their goals of maximizing resource efficiency and minimizing waste in the construction process. Application of Lean construction principles brings forth possible avenues for a constructor's involvement in green building projects.

The fourth characteristic of the "whole building" perspective can be seen as an extension of the constructability aspects of a green building project. Understanding a building as an integrated whole, comprising various systems, is of vital importance, as decisions and designs of one system very often affect the working and performance of one or more other systems (Pulaski et al. 2006). Past researchers underscore that the whole building approach is pertinent in recognizing the relationship between constructability and sustainable design (Pulaski et al. 2006, Riley et al. 2003).

Existing research also emphasizes the need for a clear definition of green objectives early in the project (Syphers et al. 2004). This requires involving all project participants, especially the constructor, early in the process in an effort to understand the complexities involved in the project and devise strategies to manage them. Constructor's early involvement also helps to streamline the downstream processes such as project planning, subcontractor coordination and preparation of construction documents (Mogge 2004). Early definition of project's green objectives can equip the constructor to plan and manage the resources required during execution and compliance with LEED®-NC requirements, such as submittals and documentation. This ties in with educating the subcontractors about the green objectives of the project and including their feedback. This is a continuous process throughout project execution and extends from preconstruction to tool box meetings, held on the job site (Klehm 2006, Toole et al. 2006).

The role of project delivery method employed in a green building project is significant because other characteristics, such as constructor's early involvement are contingent upon it. Use of design-build delivery systems is one method in which construction organizations are highly involved during project design. Use of construction manager at risk and a negotiated general contractor system also allows constructor's early involvement in the project (Kibert 2005). Such systems also facilitate the preparation of construction documents and define the required responsibilities in the subcontracts (Syphers et al. 2003). In case of hard bid projects, clear definition of the green objectives of the project is essential for obtaining a realistic project cost and avoiding high contingencies and errors and omissions (Kibert 2005).

According to Syphers et al. (2003), one of the most significant categories within the LEED®-NC rating system is Energy and Atmosphere. This category has the most points and requires increased involvement of designers, commissioning authorities, service consultants, and the constructors. Within this category, commissioning and energy modeling are the credits that can add significant upfront costs in a green building project and need rigorous monitoring. In addition, the design strategies and the responsibilities associated with these credits should be clearly defined in the construction documents for effective project planning and execution (Toole et al. 2006). A constructor's early involvement can facilitate the LEED®-NC documentation requirements for these credits.

Riley et al. (2003) called for a pronounced change in the prevalent organizational structure of construction processes. Four vital areas of estimation, green building materials, indoor air quality management, and waste minimization & recycling have been identified in the process of green construction for gaining contractor's input. The role of cost estimating during the project planning and preconstruction stage is imperative to include timely cost information concerned with green design decisions. In the case of green building materials, contractors have an increased responsibility towards educating themselves, subcontractors, and owners regarding environmental benefits of green building materials as well as ensuring their proper handling, storage and installation procedures (Riley et al. 2003, Mogge 2004). Construction waste collection and recycling, especially for a LEED® project, mandates a construction waste management plan. Similarly, maintaining optimum indoor environmental quality standards during construction requires preparation and adoption of an indoor air quality management plan (Marden 2003). In addition, use of a construction management and design build delivery system allows for greater involvement of construction teams in the design phase and has been successfully used by many government agencies seeking LEED® certification (Marden 2003, Kibert 2005).

Responsibilities identified in the literature form only a fraction of increase in the contractor's role in construction of green buildings. In addition, compliance with green building rating systems such as LEED®-NC require even more comprehensive practices, which require early involvement and a more integrated role of the construction team in successfully executing green building projects (Syal 2005). In conclusion, construction teams can provide valuable input to the owner and the design team in improving the process of delivering sustainable buildings, if involved early in the process and can be instrumental in achieving the sustainable project objectives.

2.3.2 Cost Aspects of Green Buildings

One of the major impediments to full acceptance of the LEED®-NC rating system is the concern that green buildings cost more than typical buildings. Even though the lifecycle cost of green buildings offsets the increase in upfront costs, some level of green premium is always associated with such buildings (Syphers et al. 2005). Various researchers have concluded that the amount of this green premium results from decisions made by the project team throughout the project duration (Syphers et al. 2005, Riley et al. 2005).

According to Romm et al. (1994), up-front building and design costs constitute only a fraction of the building's life-cycle costs, and when one percent of a project's up-front costs are spent, at least 70 percent of its life-cycle costs may already be committed. Thus, high initial costs have been perceived as a characteristic of green buildings and prohibitive in their acceptance and implementation by owners (Kats et al. 2003). Three important factors behind this perception are lack of life cycle costing, insufficient technical data available and an incomplete integration between project members. Several researchers have attempted to quantify these upfront costs associated with green buildings, in terms of savings accrued over the life of the building with the help of life cycle costing (LCC) (Matthiessen & Morris 2004, GSA 2004). The savings are incurred through decreased energy and water consumption, waste minimization efforts, and health and productivity benefits for building occupants (Matthiessen & Morris 2004).

Most of these cost studies have taken LEED®-NC as the reference green building rating system, due to the acceptance of LEED®-NC as an emerging benchmark for green buildings in the United States for analyzing the cost impacts (Matthiessen & Morris 2004, Kats et al. 2003, GSA 2004). One of the concerted observations made by these cost studies is the correlation between the level of LEED®-NC certification achieved and the incremental green premium incurred over the base project cost. In addition to the level of certification achieved, the project cost for a green building is also affected by factors such as project location, local and regional design standards, building codes and initiatives, bidding scenario, size of building and intent of project goals. For instance, the cost of executing construction waste management credits is significantly impacted by project location, as an urban project incurs low transportation cost and has easy access to recycling facilities (Matthiessen & Morris 2004, Syphers et al. 2003). Similarly, the bidding scenario in a project may also augment the project cost due to the constructors' perceived risk of executing a green building and increasing the contingency in the project estimate (Matthiessen & Morris 2004, Mogge 2004, GSA 2004). The upfront cost of constructing green buildings needs to be balanced against the benefits reaped by the owner in two categories of tangible and intangible benefits (Kats et al. 2003, Matthiessen & Morris 2004). Tangible benefits include savings in energy consumption, water utilization, and operational and maintenance cost savings. The intangible benefits are difficult to approximate, but include health and productivity benefits and other aspects of occupant well being.

One of the most significant conclusions drawn in the cost impact studies is that an integrated team effort minimizes the premium in green buildings. The integrated team helps to establish the green objectives of the project early on and utilize the expertise of various project members. As an important member of a project team, a constructor can provide valuable input through constructability reviews, value engineering efforts, material selection and procurement decisions and conceptual cost estimates in the early project phases to assist the designers, and help to reduce upfront costs (Riley et al. 2003, Syal 2005). Constructors have knowledge and competencies, based on their experience with green projects and lessons learned, that could be used to streamline the design process and eventually improve the project performance. Green projects, by the very nature of their complexity, lend themselves to an integrated project delivery method, providing greater opportunities for constructor's involvement to achieve sustainable project goals (Kibert 2005).

2.4 Database Systems/ Query-Based Systems and Process Models

This section focuses on existing database/query-based systems and process modeling tools that were useful in organizing the information synthesized from the two matrices developed in Chapter three and the process model developed in Chapter five.

Information technology has been established as a strong tool for disseminating construction knowledge and information in recent years (Arain and Pheng, 2006). One application of information technology, namely the database systems, has the potential to deliver solutions to decision makers, based on the knowledge collected over time (Amor and Faraj 2001). Database systems are a source for managing information contained in simple files accessed by a number of users, where duplication, redundancy, and semantic and structural heterogeneity have to be eliminated (Mackinnon et al. 1998). Similarly, Jackson (1999) identified the need for data independence and the embedding of structural and behavioral semantics in the database as key issues in the development of modern database systems such as Hierarchical, Network, Relational databases.

Shelbourn et al. (2006) discusses creation of C-SanD project (Creating, Sustaining, and Disseminating) that deals with collection and management of knowledge for sustainable construction tools, methods, and architecture. The project aimed at creating a knowledge management system, based on expert knowledge retrieved from the construction industry professionals and mapping it on a generic construction process. The architecture of the C-SanD database consisted of three principal layers. "Kernel layer" was the primary layer that helped in processing the extracted information from the knowledge base, by creating appropriate logics. The "service layer" retrieved information from different sources and acted as an extractor while the "presentation layer" acted as the user's view of functionality.

In order to facilitate the development of the process model, a research project was reviewed that dealt with the creation of generic construction process model. This research was conducted by Karhu et al. (1997), using the $IDEF_0$ model, in which activities were depicted by boxes and connected by arrows, representing the interfaces and interactions between these activities. The aim of this research was to create a generic construction process to effectively show the information flow between various construction project participants. Three hundred activities were mapped by this research, which included the activities of the owner, designer, and the general contractor. A thorough understanding of this generic construction process facilitated the researcher in developing a process model for defining a constructor's role in green building projects.

2.5 Summary

This chapter is a synthesis of the background knowledge in sustainable design and construction, which is pertinent to this research and will form the basis of different outputs presented in the subsequent chapters. Different literature categories were analyzed in order to define a coherent role of constructors in green buildings with focus on the LEED®-NC rating system.

CHAPTER THREE

PROJECT PHASE IMPACT MATRIX AND LEED®-NC CREDIT IMPACT MATRIX

3.1 Overview

This chapter develops the impact matrices of LEED®-NC requirements on construction project management practices. This work is based on the understanding developed from literature reviewed on sustainable design and construction practices, LEED®-NC green building rating system and a constructor's role and contribution in these. The primary sources of the impact matrices were the case study visits, interaction with construction industry professionals, and the input received from the Industry Advisory Group (IAG). This chapter is organized in two main sections of the Project Phase Impact Matrix and the LEED®-NC Credit Impact Matrix, as illustrated in Figure 3.1.

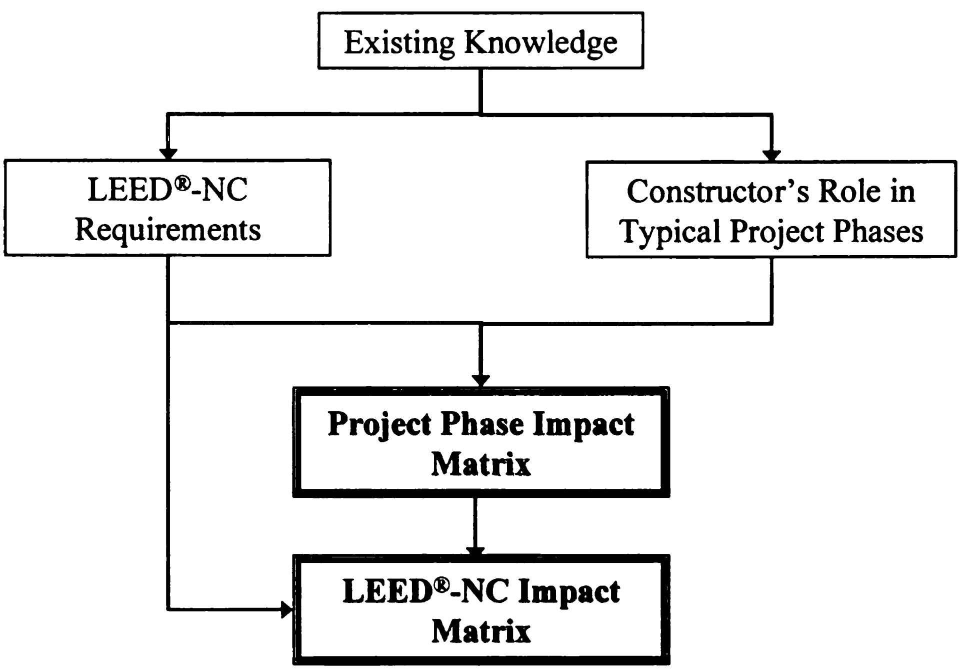


Figure 3.1: Components of Existing Research Knowledge

The output of the LEED®-NC Credit Impact Matrix was used to create the Database - Query (D/B Query) system, which will be discussed in Chapter 4. For the purpose of this research, the term constructor refers to general contractors and construction managers at risk. Before presenting the discussion of a constructor's role in green building projects and achieving the LEED®-NC credits, the researcher has presented a brief overview of a design and construction process, to outline a constructor's involvement in a typical construction project.

3.2 Typical Construction Process

The lifecycle of a typical building project can be broken down into four broad phases of feasibility, design, construction, and post construction. Each of these phases consists of several sub phases as shown in Figure 3.2 (Syal 2006). These phases involve different project participants, such as owners, designers, constructors (general contractors, construction managers and subcontractors), suppliers, and regulatory/governmental bodies.

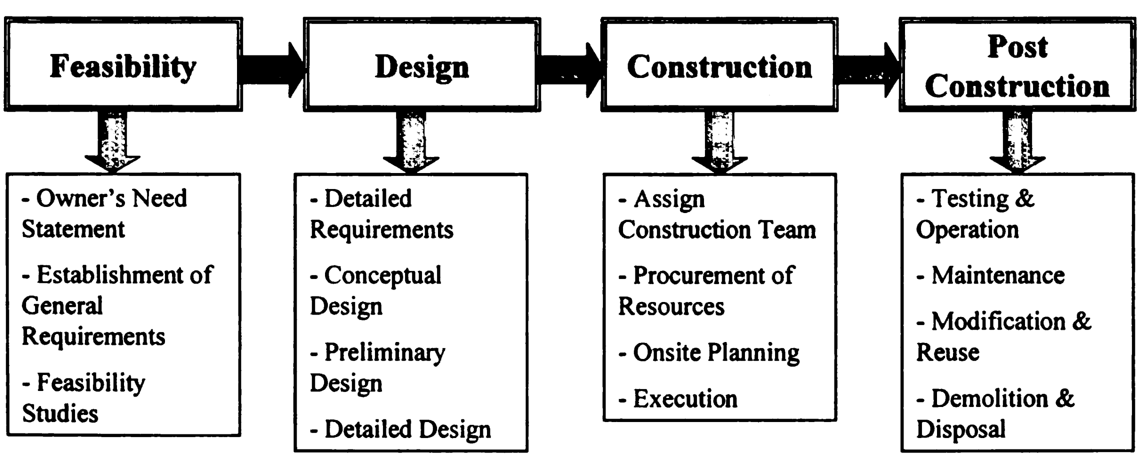


Figure 3.2: Typical lifecycle of a building project (Syal 2006)

As observed in a typical construction project, a constructor's involvement begins from the end of the design phase and continues up till the beginning of the post-construction phase (Clough et. al. 2000, Syal 2006). A constructor's involvement is also a function of the project delivery method employed by the owner as shown in Figure 3.3. For instance, in a hard bid project; a constructor is involved in the project after the design has been completed, whereas in a construction management contractual method, a constructor may be involved in the project as early as the conceptual design phase (Sweets 2004). Furthermore, in a design build contractual method, the design and construction team work together from project inception.

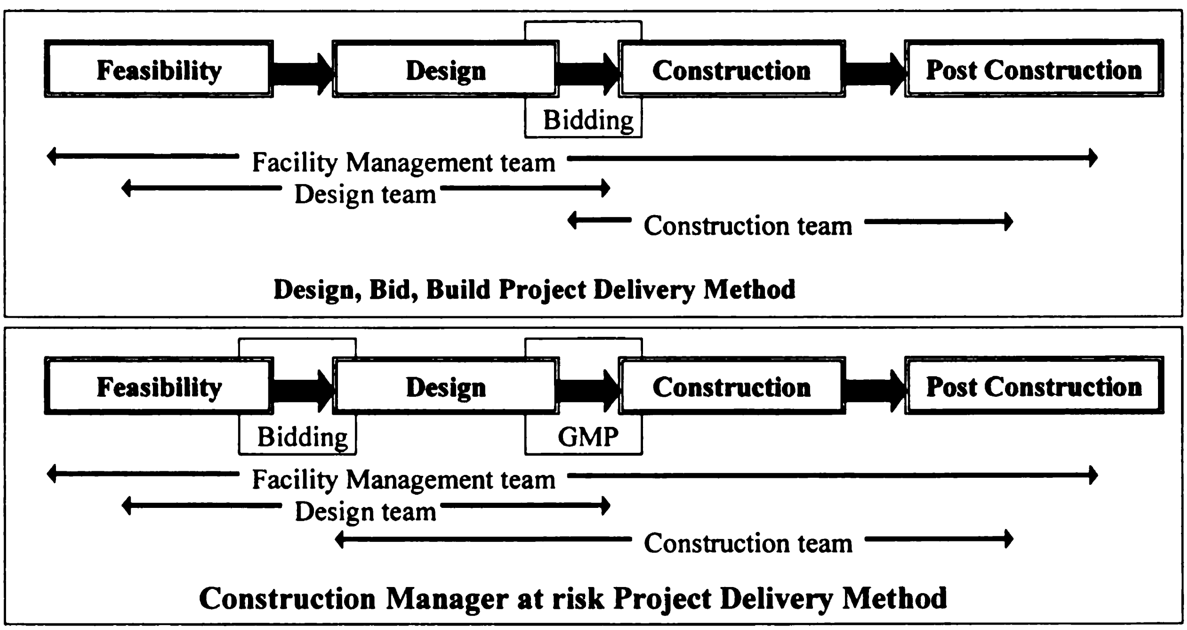


Figure 3.3: Constructor's Involvement in different project delivery methods (adapted from Sweet 2004 and Syal 2006)

In these project phases and under different contractual methods, however, there are certain responsibilities that a constructor typically undertakes. These responsibilities begin with the preparation of specifications by the designer based on the project objectives laid down by the owner, and the constructor may submit either a competitive or a negotiated bid. For submitting the project bid, the constructor prepares a project estimate based on the specifications provided and invites bids from subcontractors to include the cost of those works that will not be self-performed. With acceptance of the constructors bid, the owner and constructor sign the contract documents (Clough et al. 2000).

After this phase, the constructor's operation can be categorized under two phases of project planning and project controlling. The project planning phase begins with a review of the project estimate, preparation of the project schedule and procurement of resources (labor, equipment, materials, and others) based on the project objectives and specifications (Clough et al. 2000). In this phase, the contracts between constructor and subcontractors are also finalized. The project schedule is prepared based on the work breakdown structure of construction activities, the relationship (logic) between them and the time required to complete these activities. Project schedule also requires an assessment of resources (labor, equipment, and materials) for various activities by the constructor (Syal 2006). The project schedule represents the plan laid down by the construction team, as to how the construction on site will progress in order to meet the contract finish date.

Simultaneously, the project cost submitted for the bid is reviewed for streamlining the decisions taken during bid submission. This is followed by procurement of materials, labor and equipment, especially if there are any long lead items and any permits that may be required before work begins. The project-planning phase essentially describes the scope of the work to be done for each project participant (subcontractors), the time required to complete that part of the work and the resources (labor, materials and cost) associated with it (Syal 2006). Thus, in this phase, a set of actions or a plan is prepared for completing the project, based on the project estimate and the project schedule.

As project execution begins in the field, detailed schedules of operations are prepared from the master project schedule for execution (Clough et al . 2000). This requires resource management and financial control of the project, which together comprise the project control phase. In the project control phase, the constructor is responsible for managing the project as planned and for eliminating deviations that may arise. This phase entails preparation of project control formats, such as schedule of values purchase order system, subcontractor payment formats, cost comparison formats progress report formats, change order formats, submittal & approval formats, and other formats, to collect the data from the project as useful information, and successfully manage the project (Syal 1992). In this phase, two important variables of time and cost are either controlled separately or as a combination of two (earned value analysis). These two variables are managed based on the information collected from the field in terms of labor hours expended, work placed on site, money expended, etc. This information is then compared with the planned progress and deviations, if any are managed, till project completion (Clough et al. 2000).

Project completion is initiated with the project closeout phase, where the constructor performs numerous activities, such as preparing a closeout checklist that lists all trades that will be finishing towards the project end, closeout of subcontracts and purchase agreements, any retainages, lien releases, etc. This phase also requires the constructor to establish warranty items for any post construction work. The constructor is also required to coordinate training sessions for equipment and facilities for owner's facilities management personnel. For constructor's internal operations activities such as debriefing of project staff, analysis of estimated vs. budgeted costs, as well as cancellation of insurance on the project, have to be performed (Syal 2006).

As discussed above, a typical project delivery process is linear in its construct, where one project participant hands over part of the completed work to the next participant, and the process continues until project completion. In case of green buildings, this normative linear process results in fragmentation of the information as it passes from one phase to the other and the gaps formed due to this fragmentation result in increased cost of green buildings (Mogge 2004).

The need arises for a more integrated team approach that utilizes the expertise of all project participants to achieve the sustainable project goals. Moreover, a definitive understanding of sustainable project objectives by all project participants is imperative for removing any information gaps. As the constructor is incorporated in the project team when some of the critical decisions may have already been taken, the project team may not able to realize the benefits of a constructor's expertise and input in the initial project phases in order to achieve the sustainable project objectives more effectively (Mogge 2004, Riley et. al 2004).

3.3 LEED®-NC Green Building Rating System - Constructor's Role

The LEED®-NC Green Building Rating System consists of six categories, which address different building elements and define a set of performance-based standards with which the buildings comply in order to be certified. The focus of these categories covers aspects that the built environment either affects or is affected by, extending from site development to energy consumption, including indoor environmental quality for occupant well being (Vijayan & Kumar 2005). Within these six categories, certain elements have been determined which the project has to include in order to receive certification. These prerequisites are in the categories of sustainable sites, energy and atmosphere, materials and resources, and indoor environmental quality. The certification process begins in the design phase of the project, and continues through the construction phase with documentation and submittals in support of compliance with the LEED®-NC requirements. The project teams can submit documentation for compliance with credits during the design and construction phase or after the construction is complete (Fowler and Rauch 2006). Project teams are allowed to have one design phase review and at the end of the construction phase, the design credits are reviewed for follow up for as planned completion, in addition to the construction credits (LEED 2005).

This section discusses the role of a constructor in complying with the LEED®-NC requirements. From all six categories, a constructor's involvement is predominant in the three categories of Energy and Atmosphere, Materials and Resources and the Indoor Environmental Quality, due to greater emphasis on "during construction" activities and submittal requirements (Riley et al. 2004). All LEED®-NC categories present opportunities for involving a constructor early in the project, however, in order to bring greater expertise and technical background through value engineering and constructability reviews. For instance, it was observed in case study project "D" that construction specification required installation of waterless urinals that added to the project cost and required greater maintenance during building operation. The constructor involved with the project suggested an alternative of a combination of low flow urinals. The suggestion was based on calculation of minimal water consumption in the building in order to achieve the requirements of both WE credit -2 (Innovative Waste Water Technologies) and WE credit - 3 (Water Use Reduction) (Gardi 2007).

Early involvement of the constructor also helps to coordinate its own workforce, subcontractors and suppliers based on the LEED®- NC requirements of the project. For instance, in achieving the Materials and Resources Credits, more than just completing the submittal requirements, the constructor's knowledge of material sourcing and procurement should be utilized. As MR Credit - 5 (Regional Materials) requires use of materials that are manufactured/harvested or both within a radius of 500 mile of the project, a local constructor's expertise in material procurement should be realized while preparing project specifications. Moreover, a constructor's early involvement in a green project will bring clarity in terms of duties and responsibilities for constructor's self-operations.

As the estimators, schedulers, project managers and field personnel are all aware of LEED®-NC requirements, their compliance is more streamlined and effective. For instance, the schedulers during the project control operations would be aware of activities that may be necessary due to LEED®-NC requirements such as EA Prerequisite-1 (Fundamental commissioning) and thus not appropriate for project control actions. In addition, the constructor's team can further educate the subcontractors in terms of their duties and responsibilities for the LEED® requirements and effectively manage the subcontractor's activities during construction for compliance. Based on a similar discussion, the subsequent sections elaborate on a constructor's role in contributing to a green building process based on project phases (Project Phase Impact Matrix) and LEED®-NC Credits (LEED®-NC Credit Impact Matrix).

In order to supplement the impacts identified in the two matrices, two sources were useful, the case studies and the Industry Advisory Group (IAG). The function and constitution of these is discussed in the next section.

3.4 Case Studies and Industry Advisory Group

Four case study projects were studied along with existing literature to develop a preliminary analysis. This analysis is discussed as the project phase impact matrix. In order to supplement the preliminary analysis and develop the LEED®-NC credit Impact Matrix, the industry advisory group (IAG) provided examples of current practices in green buildings based on experience with LEED®-NC projects and lesson learned. The final output of the LEED®-NC Credit Impact Matrix was presented to the IAG and their input was incorporated.

3.4.1 Case Study Projects

This research was done under a research initiative at Michigan State University, supported by the William A. Klinger Memorial Research Award, AGC Education and

Research Foundation and the Environment Research Initiative (ERI), Michigan State University. The case study projects and the IAG are part of this research initiative.

3.4.1.1 Case Study Selection Process

The selection of case studies was based on the willingness of the LEED® project teams to share information and their experiences. As the focus of this research was LEED®-NC, all case study projects were commercial buildings. The case study projects were either LEED® –NC certified or in the process of achieving the certification. Four projects were studied; two projects were already certified, one was under construction, and the fourth project was in the planning phase. The diversity of these case studies, by virtue of being in different project phases, facilitated the researcher's understanding of the impacts on a constructor's role in LEED® projects. In addition, two projects were certified for a Gold and Platinum LEED®-NC rating respectively, while the other two projects were aiming at Gold and certified rating level respectively. This pool of different LEED®-NC rating levels provided a wide range of impacts on a constructor's role and involvement in LEED® projects.

Case Study A: Case study – A is a healthcare building and was the primary project reviewed. It is a healthcare facility with an area of 397,000 sf. The project is pursuing a certified rating under LEED®-NC V 2.0. This project is towards completion and the constructor was in the process of compiling the LEED®-NC documentation when reviewed. This project provided information pertaining to most of the major impact credits as discussed in the LEED®- NC credit impact matrix.

Case Study B: Case study – B is an office building, which is Platinum rated under the LEED® - NC V 2.0. The building was in operation when the case study was conducted. As this project achieved a platinum rating, the project planning team shared information pertaining to the constructor's role in the project planning, execution and post construction phase. This building is built on a Brownfield site and reused an existing industrial site that provided insight into a constructor's role in achieving moderate impact credits such as SS C-3 Brownfield Redevelopment and MR C-2 Building Reuse. In addition, this project achieved some of the Innovation and Design credits for exemplary performance and design innovation.

Case Study C: Case study – C is an industrial facility and is gold rated, under LEED® - NC V 2.0. This project was in operation when reviewed and most of the credits achieved by this facility were major impact credits as identified in the LEED®-NC credit impact matrix.

Case Study D: Case study – D is an office building aiming for gold rating. This project was in the planning phase when reviewed and the constructor's role in the preconstruction phase of providing value engineering input, as well as undertaking constructability reviews, was significant.

3.4.1.2 Case Study Data Collection Process

For each case study, the project planning team was interviewed for information for each attempted LEED®-NC credit and its impact on the following construction management functions. These were derived from the Project Phase Impact matrix.

- Estimation and Project Cost

- Scheduling – Activity durations, logic and sequence
- Project Administration and Documentation
- Contracts and Agreements
- Field Operations and Subcontractor Coordination

The interviews were held as informal discussions and the impact on project teams' activities in order to achieve the LEED®-NC credits was obtained. In the following section, a brief description of the case study projects is provided. The case studies are coded as A, B, C and D, in accordance with the requirements of Institutional Review Board (IRB) at Michigan State University.

3.4.2 Industry Advisory Group

In addition to the case study projects, an Industry Advisory Group (IAG) was formed, which provided continuous input in this research. They provided contact information of other design, construction and commissioning professionals with whom they had worked on LEED® projects.

3.4.2.1 Industry Advisory Group Selection Process

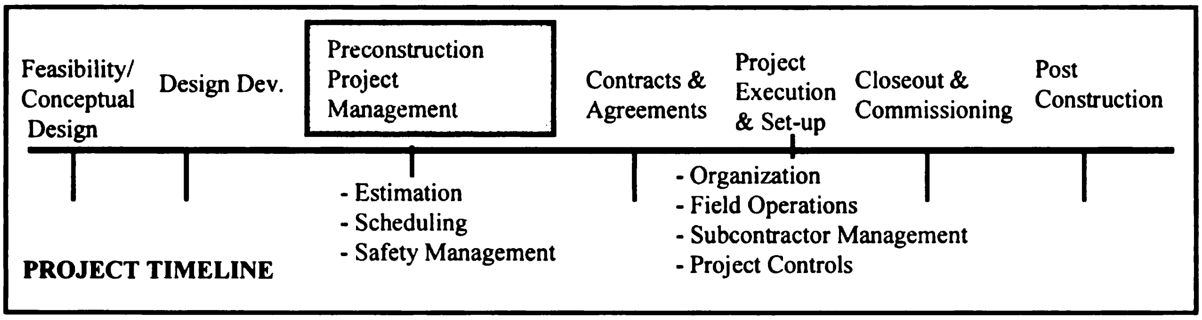
The main IAG members were contacted through MSU conduction management alumni. These members gave information of other design and construction professionals with experience in LEED® projects. The IAG was comprised of members with different professional backgrounds such as architects, facility managers, project managers, estimators, mechanical designers, cost engineers, project superintendents, and LEED® coordinators. Eighteen IAG members gave permission to use their names and professional affiliations and are mentioned herein while others are designated in accordance with MSU-IRB regulations. The LEED®-NC Credit Impact Matrix was presented to the IAG in December 2006, at a meeting hosted at Michigan State University and their feedback was incorporated in the matrix. The LEED®-NC Matrix is part of the AGC Klinger award workshop manual. During spring and summer 2007, the LEED®-NC Impact Database Application and the role of constructors in different contractual relations was presented to the IAG members and their input was incorporated.

3.5 Development of Project Phase Impact Matrix

The impact matrices were developed, based on how a constructor can contribute in achieving LEED®-NC credits and how these credits impact the constructor's processes and activities. In order to address these aspects, the researcher developed the Project Phase Impact Matrix, based on literature reviewed.

3.5.1 Organization of Project Phase Impact Matrix

In this matrix, in each project phase, the constructor's role in achieving LEED®-NC credits was analyzed based on the literature reviewed. The design of this matrix consists of the project phase, constructor's role/ activities, and an example/explanation to supplement the constructor's role. Figure 3.4 illustrates an example of this matrix, for the Preconstruction phase, in which the project cost may be affected due to IEQ LEED® requirements, which should be considered by the constructor in determining the project cost.



Project Phase	Constructor's Role /Activities	Example/ Explanation
Preconstruction Project Management	1) Project Cost may be affected by temporary services required to maintain optimum IEQ standards, for compliance with LEED credits during construction (Horman et al. 2006, Riley et al. 2003).	1) In order to maintain optimum IEQ during construction, the HVAC system for the building might be used or a temporary system might be installed. Cost of temporary HVAC systems / special filters that may be required, should be incorporated in the project estimate

Figure 3.4: Structure of Project Phase Matrix

The illustration depicts the impact on the project cost due to additional cost required for temporary/permanent ventilation systems used during construction. The project phase matrix was developed based on typical design and construction phases in a project. These phases were further elaborated with input from the literature review, to include various sub-processes, in order to define the role of a constructor more effectively. Figure 3.5 shows the project phases and sub phases used in this matrix.

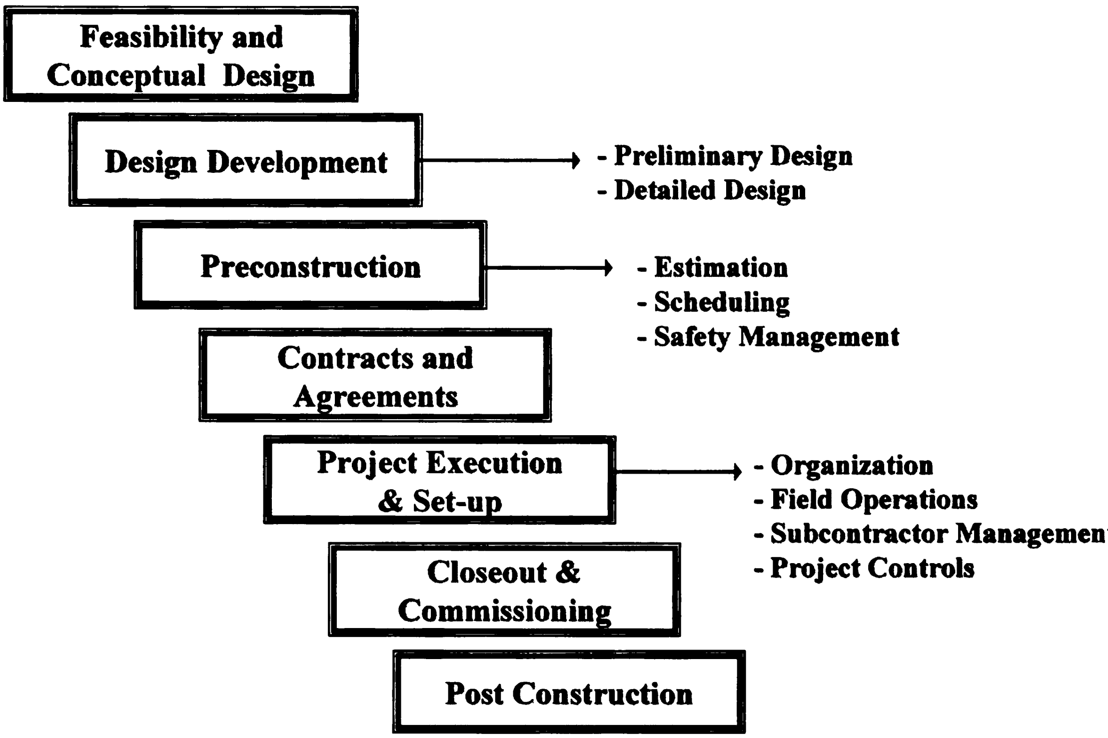


Figure 3.5: Project phases and sub phases used in Project Phase Impact Matrix

In the next section, an example of the project phase matrix, with a constructor's role in the preconstruction phase, is illustrated. For the reader's reference, the complete matrix is included in the report titled "Impact of LEED®-NC Projects on the Construction Industry", developed as a part the Environmental Research Initiative, Environmental Science and Policy Program (Syal and Mago 2007b).

3.5.2 Project Phase Impact Matrix Example – Preconstruction Project Management

Feasibility & Conceptual Design	Design Development (Prelim & Detailed)	Preconstruction Project Management	Contracts & Agreements	Project Execution & Set-up	Closeout & Commissioning	Post Construction
PROJECT TIMELINE		-Estimation -Scheduling -Safety Management		-Organization -Field Operations -Subcontractor Management -Project Controls		

Table 3.2: Project Phase Impact Matrix – Preconstruction Phase

Project Phase	Constructor's Role	Remarks / Resources
Pre-construction Project Management	**Estimation**	
	1. Project Cost affected by a) Temporary services required to maintain optimum IEQ standards, for compliance with LEED® credits during construction (Horman et al. 2006, Riley et al. 2003). b) Storage and installation of green materials (Syphers et al. 2003). c) Construction Waste separation on site and its recycling or reuse. d) LEED® documentation & LEED® consultant. e) Additional R&D capabilities required for green building materials (Riley et al. 2003). f) Certification of Green building materials, products, and systems (Syphers et al. 2003). g) Specialized training for sub contractors and other down stream project participants. h) Extra bonding and insurance requirements for a LEED® project. i) Site logistics planning, temporary barricading and pollution prevention costs.	1) (a) In order to maintain optimum IEQ during construction, the HVAC system for the building might be used or a temporary system might be installed. Cost of Temporary HVAC systems / special filters that may be required, should be incorporated in the project estimate. (f) The construction team may be required to source out and develop a database of green materials, which will be used for the project in order to facilitate subcontractors and project engineers on site. (i) The responsibility associated with achieving LEED® certification increases with increase in the level of certification being achieved. As a constructor's responsibility increases on a LEED® project, there might be a potential increase in the constructor's liability, which may trigger increased bonding and insurance requirements.

Table 3.2 (cont'd)

Project Phase	Constructor's Role	Remarks / Resources
	2. Cost of commissioning requirements during design, construction and close out.	1) Cost of commissioning will vary based on which commissioning credit is being aimed at. The fundamental commissioning credit, which is a prerequisite, requires start up and testing of the designed building systems. The enhanced commissioning credit, however, requires a comprehensive review of the design to ensure that the constructed system would work as intended. The enhanced credit entails a review during system design and construction. Thus, enhanced commissioning credit may become an additional cost item in the project estimate.
	3. Special transportation and handling associated with green building materials and products (Riley et al. 2003).	
	4. Undertake Lifecycle Cost Analysis of the project (Syphers et al. 2003).	
	5. In case of major renovation projects, the constructor has to expend due care for salvage - both for cost savings and LEED submittal requirements.	1) MR Credit 1: Building Reuse – requires detailed calculation of the percentage of existing building maintained.
	6. Incorporate the LEED® credits in the cost codes, cost breakdown structure, and schedule of values.	

Table 3.2 (cont'd)

Project Phase	Constructor's Role	Remarks / Resources
	7. Prepare detailed schedule of values for determining the total material costs and the percentage of this value that qualifies for the material reuse and recycled content. In addition, the constructor is responsible for collecting the detailed calculations for materials reuse and recycled content from the subcontractors.	1) As both MR credit 3 (Material Reuse) and credit 4 (Recycled Content) require the percentage calculation to be done based on the total value of materials used in the project, the constructor is responsible for preparing these calculations based on the schedule of values prepared.
	SCHEDULING	
	Additional Activities	
	1. Commissioning and inspection to be included as extra activities in the project schedule.	1) Commissioning reviews and inspections for compliance with green objectives of the project have to be conducted during specific project phases when the respective activities (related to certain credits) are being executed. This requires inclusion of commissioning reviews in the project schedule.
	Effect on Activity Duration	
	1) Duration of certain activities may increase, due to compliance with IAQ management plan during construction.	1) Installation of building materials that release airborne contaminants may require increased "curing" period, and additional ventilation. This will increase the duration of such activities.
	2) Lead-time for green building materials should be incorporated in the project schedule.	

Table 3.2 (cont'd)

Project Phase	Constructor's Role	Remarks / Resources
	3) Installation of new materials and use of new construction methods might increase the activity durations.	1) Such a productivity analysis might be required if the work crews are not familiar with green construction materials or methods or the design entails a complex construction method.
	Effect on Sequence and Logic of Project Schedule	
	1. Sequencing of activities and inclusion of additional activities in accordance with IEQ management plan (Riley et al. 2004). Installation of construction materials that release high levels of VOCs should be done by allowing enough time in the installation of subsequent "sink" materials or those materials that can readily absorb these VOCs.	1) "Highly absorbent materials (ceiling tiles, gypsum wall board, fabric furnishings, carpet and insulation, for example) will act as 'sinks' for VOCs, odors and other contaminants; therefore it is advantageous to install VOC-emitting products BEFORE installing absorbent materials" (LEED® CIR- 8/16/2002). 2) "Move-in of hard surface fixture, furnishings and equipment (FF&E) should occur during the flush period, but soft or porous FF&E items should be delayed until after the flushing cycle" (LEED® CIR- 5/15/2003).
	2. Including lags in those activities that are bound to generate air contaminants and affect the optimum IAQ requirements (Mogge 2004).	1) "Flush-out to be conducted AFTER substantial completion of construction (including major IEQ-relevant punch list items) and prior to occupancy" (LEED® CIR- 3/8/2004).

Table 3.2 (cont'd)

Project Phase	Constructor's Role	Remarks / Resources
	3. Activities impacting the sequence:- a. Site erosion requirements b. Lead times for material delivery of green products. c. Compliance with commissioning requirements during construction. d. Preparation and execution of commissioning punch list for LEED® certification.	
	Safety Management	
	1) In case of Brownfield redevelopment projects, the constructor has additional responsibility for worker safety on the job site in context of abatement of contaminants (Klehm 2006).	

3.5.3 Analysis of Project Phase Impact Matrix

After developing the project phase impact matrix, certain patterns in a constructor's involvement in a LEED® project were apparent. These observations facilitated the development of the second matrix and are discussed below.

- One of the important observations in the project phase impact matrix was the identification of project phases in a LEED® project in which the constructor's involvement was most significant. These project phases were Preconstruction, Contracts and Agreements, and Project Execution and Set-up. These project phases were further emphasized in the LEED®-NC credit impact matrix as discussed in the subsequent observations.
- In addition, certain sub processes under the different project phases surfaced as separate functions that a constructor performs in a LEED® project due to the significant impact on them. For instance, under the activities of "Estimation" and "Scheduling", in the Preconstruction phase, several impacts were identified in the project phase impact matrix. Thus, in the LEED®-NC Credit Impact Matrix, these sub processes were considered as individual functions of a constructor. The project control sub process, from the Project Execution phase, was included in the Estimation and Scheduling functions due to its specific relationship with time and cost and any impact identified for project control aspect was mentioned under the "Estimation" and "Scheduling" functions. Thus, these functions are discussed in greater detail in the LEED®-NC Impact Matrix.
- As documentation is an important aspect in a LEED® project, and most of the construction credits require documentation, a constructor's active role in

providing this documentation to the owner and collecting it from its subcontractor is imperative. Therefore, a separate category of "Project Administration and Documentation" was created that included the general project responsibilities of a constructor, and focused on the LEED®-NC documentation aspects.

- Similarly, the Field Operation, Subcontractor Management, and Safety Management activities were organized as one construction management (CM) function of "Field Operations and Subcontractor Coordination" for analyzing the impacts in the LEED®-NC Credit Impact matrix.
- Moreover, it was observed that a constructor's responsibilities/activities for the Commissioning phase were not as continuous and rather intermittent and dependent on other phases such as Contracts and Agreements and Project Execution sub phases.
- The feasibility and design development project phases were not included as separate functions in the LEED®-NC Credit Impact Matrix, as a constructor's involvement in these phases is project specific and may vary base on project delivery method adopted and the contractual obligations of the parties involved. The impacts mentioned in the project phase impact matrix, however, present immense opportunities for involving a constructor in these project phases and utilizing their expertise. In the LEED®-NC credit impact matrix, such instances have been included as scenarios for those credits, which are mostly design intensive, such as SS credit -1: Site Selection.
- Certain requirements of a green building process, which do not relate to any of the CM function but affect the constructor's activities, are included in a separate

section of "other constructor related". Although these activities may not directly relate to constructor's typical responsibilities in a construction project, but they help to reinforce the case for the constructor's early involvement in a LEED® project to effectively achieve the green objectives and streamline the green building construction process.

3.6 Development of LEED®-NC Credit Impact Matrix

This section focuses on the development of the LEED®-NC Impact matrix. It establishes the relationship between the Project Phase and LEED®-NC Credit Impact Matrix and builds further on the analysis of the project phase impact matrix. The organization and components of the LEED®-NC matrix are discussed along with examples of three levels of impact, identified for the LEED®-NC credits.

3.6.1 Relationship between Project Phase Impact Matrix and LEED®-NC Credit Impact Matrix

The previous section entailed a discussion of a constructor's contribution in a LEED® project, defined under different project phases. This section deals with a similar discussion, with focus on impact of LEED®-NC credits on a constructor's role/activities in a construction project. The Project Phase Impact Matrix provided a constructor's broader zone of influence in a LEED® project, and the LEED®-NC Credit Impact Matrix narrows this influence by synthesizing a constructor's role under specific Construction Management (CM) functions such as "Estimation" and "Scheduling".

Based on the major project phases in the first matrix, a set of CM Functions were identified that depicted a constructor's significant involvement in a LEED® project. Thus, the first matrix helped to create a rubric for the second matrix, as discussed in the observations made from the Project Phase Impact Matrix. In addition to the project phase impact matrix, the LEED®-NC credit impact matrix was also supplemented by information collected from the case study projects, which highlighted instances of a constructor's involvement in LEED® projects. The Project phases and their sub processes identified from the project phase matrix were used as CM functions, to identify the impacts in the LEED®-NC Credit Impact Matrix, as shown in Figure 3.6.

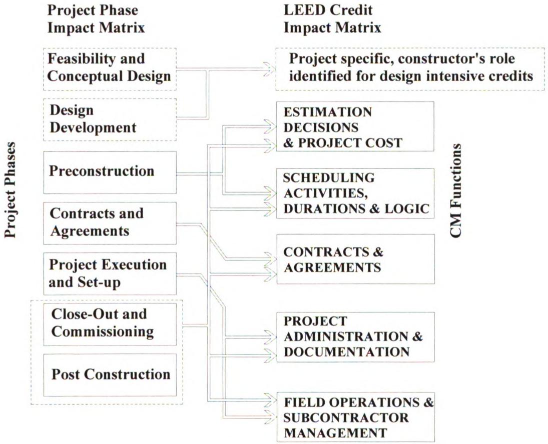


Figure 3.6: Development of CM functions from Project Phases

3.6.2 LEED®-NC Credit Impact Matrix

In this matrix, LEED®-NC credits were taken as the base structure and for each credit, under the CM functions mentioned above, the constructor's role was identified. The LEED®-NC credits were further categorized under the three levels of impact; major, moderate, and some, as shown in Figure 3.7. These impact levels are representative of the extent of a constructor's involvement in a LEED®-NC project as discussed in this section.

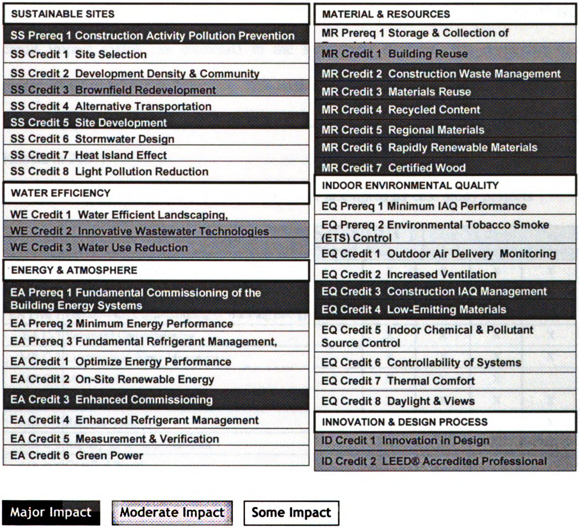


Figure 3.7: Categorization of LEED®-NC Credits as Major, Moderate and Some impacts

The major impact credits include the construction intensive credits such as MR – 2 Construction Waste Management. The moderate impact credits include those that are both design and construction related and the constructor's involvement will benefit the project team in compliance with LEED®-NC certification system. Some impact credits are those which are primarily design oriented and may benefit due to a constructor's input. One of the primary observations in the case studies was that these projects achieved/attempted most of the major impact credits, as identified in the LEED®-NC credit impact matrix, as discussed in the subsequent sections. The researcher has presented these credits in Table 3.1. This method of assimilation of credits attempted by case study projects was adapted from a thesis completed at Michigan State University by Khosla in 2007.

Table 3.1: Major Impact Credits achieved/ attempted by case study projects

MAJOR IMPACT LEED-NC CREDITS ACHIEVED		Case Study-A	Case Study-B	Case Study-C	Case Study-D
SS Preq 1	Construction Activity Pollution Prevention	X	X	X	X
SS C-5	Site Development	X	X	X	X
EA Preq 1	Fundamental Commissioning of Building Energy Systems	X	X	X	X
EA C-3	Enhanced Commissioning	X	X	X	X
MR C-2	Construction Waste Management	X	X	X	X
MR C-3	Materials Reuse	X	X	X	
MR C-4	Recycled Content	X	X	X	X
MR C-5	Regional Materials		X		X
MR C-6	Rapidly Renewable Materials	X	X		X
MR C-7	Certified Wood				
EQ C-3	Construction IAQ Management Plan	X	X	X	X
EQ C-4	Low-Emitting Materials	X	X	X	X
X	Credit Achieved/Being Attempted				

The categorization of credits was developed and refined through a gradual process based on literature reviewed, researcher's training obtained from LEED®-NC technical reviews, research team discussions, observations from case studies and informal interviews held with case study project teams. While identifying these categories, it was observed that certain credits, in spite of being design specific, might be more effectively achieved due to a constructor's early involvement and input. For instance, the intent of credit SS – 1 Site Selection is to reduce or eliminate development of inappropriate sites to decrease the environmental impact of a building on a site. A constructor's input in achieving this credit is significant, if the project is being constructed for a developer. As the developer may intend to lease the facility once completed, a construction manager may be responsible for selecting an appropriate site that complies with the LEED®-NC requirements. Thus, in such a project, the constructor is responsible for the site and the building and the site location should be such that can provide all the LEED®-NC credits desired by the client. The above scenario illustrates one of those credits that might require a constructor to be involved early in the project, based on the project requirements.

Another "some impact" credit is EQ – Prereq-1 Minimum Indoor Air Quality Performance, which requires "establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants" (LEED 2005). In compliance with this credit, the constructor may be required to include all procedures necessary for compliance with the IAQ management plan while preparing the bid document for subcontractors. In case the constructor is involved early in the project, during the site selection phase of the project, the owner, the design team, and the constructor should consider any polluting elements or sources, in the vicinity of the site, that may have a negative impact on the building over its lifecycle (LEED 2005). The constructor may also plan for activities occurring during the construction process that may act as cause of future air quality contamination (LEED 2005). For instance, covering of air-conditioning ducts during construction restricts the entry of dust particles, which once the building is operational, may negatively affect the occupant health. The major impact credit EQ 3.1 (IAQ Management during construction) deals with such construction activities and ties in with this point. In addition, the impacts identified for certain LEED®-NC credits on a constructor's activities were similar, and were accordingly grouped. For instance in the MR category, credits 3-7 (Materials Reuse, Recycled Content, Regional Materials, Rapidly Renewable Materials and Certified Wood) are discussed under one section in the LEED®-NC credit impact matrix as shown in Figure 3.8. This grouping of credits can help the constructors' to effectively plan their operations for green building projects.

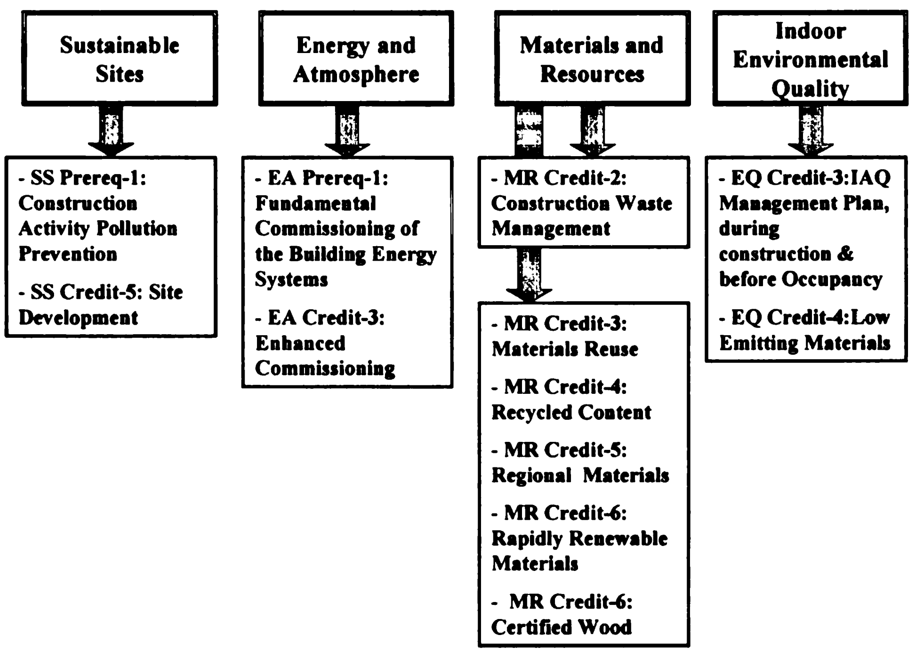


Figure 3.8: Major Impact LEED®-NC Credits

3.6.2.1 Organization of LEED®-NC Credit Impact Matrix

The design of the LEED® Credit matrix consists of four elements, the LEED® Credit, constructor's role/ activities as a Discussion Point, an Example/Explanation to supplement the constructor's role and a Reference section that includes any figures/pictures, etc. as shown in Figure 3.9. Each of these four elements is defined for each CM function.

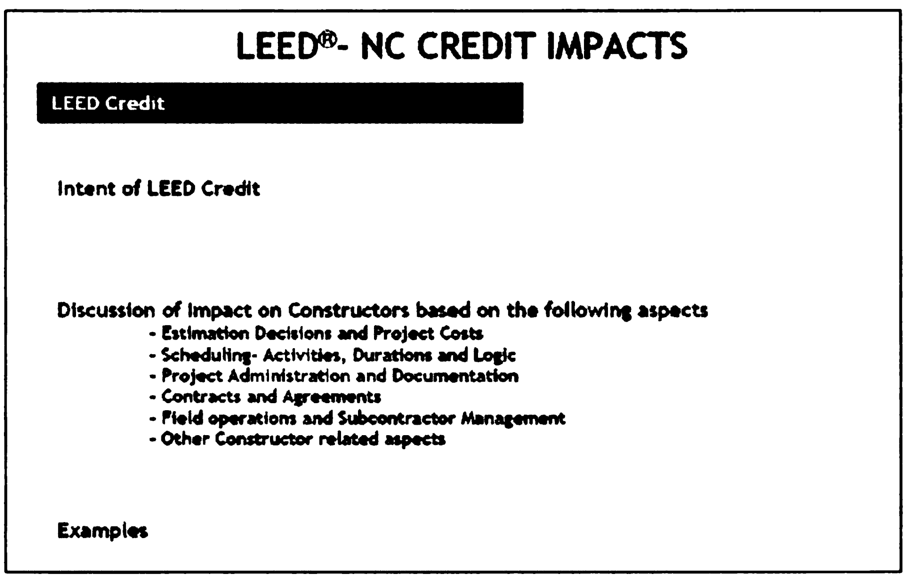


Figure 3.9: Structure of LEED®-NC Credit Impact Matrix

3.6.2.2 Process of Preliminary Analysis and Data Finalization

Based on the literature reviewed, data collected from the case study projects, project phase impact matrix and research group's experiences, a preliminary determination was made to categorize various LEED® prerequisites and credits in three levels of impact on constructors - "Major," "Moderate" and "Some." In addition, preliminary discussions points and examples for each prerequisite and credit were developed. These impact levels with corresponding discussion points and examples were presented to the IAG in a half-day session held at Michigan State University. The IAG provided input in finalizing the categorization of credits under major, moderate and some impact categories and the discussion points. Another significant input of the IAG was in providing examples to supplement the discussion points and the final LEED®-NC credit impact matrix was sent to the IAG for feedback. In the following section, a constructor's role is identified in all the LEED® –NC Credits, which are categorized according to three levels of impacts mentioned above. In each of the impacts identified, an explanation is provided for a better understanding of the reader. An illustration of major impact and moderate impact credits is discussed in detail in the next section.

3.6.2.3 Major Impact Credit – MR Credit -2: Construction Waste Management

In this section, analysis of MR C-2 Construction Waste Management on the CM function of estimation and project cost is presented in Figure 3.10 - 3.13.

LEED®- NC CREDIT IMPACTS

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

Divert construction and demolition debris from landfills and incinerators. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.

ESTIMATION DECISIONS & PROJECT COST

1. The constructor needs to assess the recycling facilities near the project site. The cost of implementing a Construction Waste Management (CWM) Plan is a function of various project specific factors such as (Matthiessen & Morris 2004, Mogge 2004, Katz et. al. 2003) :
    - Project location - It is an important factor that affects the cost of implementing a Construction Waste Management Plan. For instance, projects located in downtown areas may have space constraints, which may not allow sorting of waste on site. Consequently, construction waste may be collected as commingled waste on site and waste separation may be done outside the site premises, which may increase the cost of CWM significantly.
    - Site logistics and building layout planning - The project team may decide to rent a space for waste collection and/or sorting outside the project premises due to lack of space on site, increasing the project overhead cost (Winn 2006).

Figure 3.10: Estimation Decisions and Project Cost – Slide 1

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

ESTIMATION DECISIONS & PROJECT COST

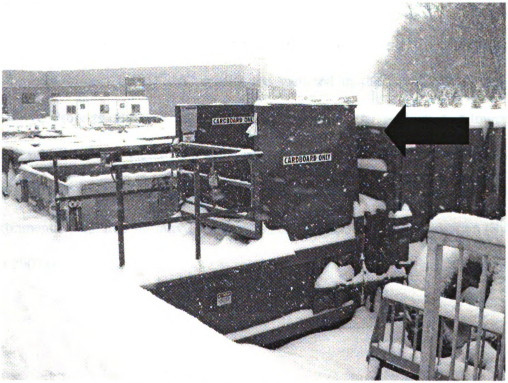
- Availability of recycling facilities- It may impact the cost of hauling the waste from the project site to the recycling facility. It may also influence the option of on site waste sorting or commingled waste recycling.

Examples:

a. In "Case Study Project - B" about 93% of all construction and demolition waste (6,000 tons) was diverted from landfills. A "gyp monster" was used to grind drywall for use as a soil amendment. The original office building was deconstructed and used as structural fill to help raise the entry roadbed (Case Study Project - B 2007).

b. In "Case Study Project - A," the project team used a cardboard compactor to offset the cost of collecting and sorting the waste on site (Case Study Project- A 2007). The compactor used is shown in the next slide.

Figure 3.11: Estimation Decisions and Project Cost – Slide 2



Cardboard Compactor used in "Case Study Project - A" (2007)

Figure 3.12: Estimation Decisions and Project Cost – Slide 3

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

ESTIMATION DECISIONS & PROJECT COST

2. The constructor may be required to create separate cost codes for assigning the cost associated with waste diversion on the project.

Example:

a. One of the aspects that affected the project control formats, in "Case Study Project- B", was the creation of a separate cost code for construction waste hauling and recycling. The project team created a separate line item in the project estimate for hauling and recycling the construction waste. After mobilization, the recycling unit provided monthly invoices to the project team for items that were recycled. Cost from these invoices was then transferred to the construction waste cost code. This acted as a record for measuring the quantity of construction waste diverted and the corresponding cost incurred (F1 2007).

Figure 3.13: Estimation Decisions and Project Cost – Slide 4

For the reader's reference, all CM functions for MR C-2 are included in Appendix A. All major impact LEED®-NC credits are included in the report titled "Impact of LEED®-NC Projects on Constructors", submitted as a part the William A. Klinger AGC research project. The moderate and some impacts credits are included in the report titled "Impact of LEED®-NC Projects on the Construction Industry", developed as a part the Environmental Research Initiative, Environmental Science and Policy Program (Syal and Mago 2007a).

3.6.3 Moderate Impact Credit – ID Credits

As an illustration, for moderate impact credits, the researcher has presented a discussion of the Innovation and Design Credits. This LEED®-NC category is unique, as it is open-ended and provides immense opportunities for utilizing a constructor's input in the green building process. It also reinforces the need for an integrated design process, which allows the project team to draw from the knowledge of various project participants. The impacts identified for this category are based on a different approach, as there are no predetermined performance standards, as defined for other credits. Points in this category are achieved by two methods, namely exemplary performance in the existing credits and/or use of an innovative solution, which addresses the sustainability goals of the project and serves as an example to be used in other projects.

This research identified a constructor's role in achieving these credits, based on the exemplary performance credits and the Credit Interpretation Requests (CIR), submitted for this category. The first method of exemplary performance sets a benchmark higher than the existing credit requirements, and therefore necessitates a greater commitment from the project team. Further, the credits in which exemplary performance is allowed are primarily the major impact credits, as identified in this research and shown in Figure 3.14. Thus, a constructor's role becomes pivotal in achieving these credits and exceeding the benchmark and attaining the ID points. As a result, a greater commitment is required from the project members: both the design and the construction team, specifically subcontractors, field personnel and all members involved in the project from the constructor's organization.

SUSTAINABLE SITES
SS Credit 4 Alternative Transportation
SS Credit 5 Site Development
SS Credit 6 Stormwater Design
SS Credit 7 Heat Island Effect
WATER EFFICIENCY
WE Credit 2 Innovative Wastewater Technologies
WE Credit 3 Water Use Reduction
MATERIAL & RESOURCES
MR Credit 2 Construction Waste Management
MR Credit 3 Materials Reuse
MR Credit 4 Recycled Content
MR Credit 5 Regional Materials
MR Credit 6 Rapidly Renewable Materials
MR Credit 7 Certified Wood
INDOOR ENVIRONMENTAL QUALITY
EQ Credit 8 Daylight & Views

Figure 3.14: Exemplary Performance LEED®-NC Credits

The second method requires the project team to develop an innovative solution and/or a design approach that addresses a sustainability issue relevant to the project. In addition to the innovative design solutions, the CIRs reviewed include two common issues of community education on benefits of green buildings and green housekeeping and operations efforts, which have been successfully approved by the USGBC (LEED CIR 2006, IAG 2006) as shown in Figure 3.15 have been successfully approved by the USGBC (LEED CIR 2006, IAG 2006).

1. "Inquiry for Educational Program - (Successfully Attempted Example)
To educate a broad audience about sustainable design, especially the sustainable solutions integrated into the MEF project. Target audience will include Pentagon occupants, Pentagon Renovation Program staff, Federal Facilities Division staff, users of the Pentagon Metro stop, and the general public.
Ruling
The elements described suggest that the project is on its way to achieving an education ID credit. Specific requirements for an education ID credit have been established by the USGBC through previous CIR's. When submitting this credit, make sure the documentation adequately addresses the requirements listed in previous CIR's, such as CIR 0097-IDc11-092801 dated 9/24/01. (LEED ID CIR, 1/13/2003)"

Figure 3.15: Successful attempt for the Innovation and Design credit

This method may be very project specific and dependent on aspects such as the owner's need and nature of the project. The commonality of the ID strategies accepted by USGBC lies in their intent that serves a broad section of users and has a bigger and lasting impact on the public. In contrast, one of the unsuccessful attempts in the ID category deals with educating the subcontractors about the green project goals. As shown in Figure 3.16, this strategy was rejected by USGBC, as it is expected as a best practice and is not innovation.

2. **"Subcontractor Training Program (Unsuccessfully Attempted Example)**
   To exceed LEED requirements and obtain an innovation credit, the contractor is proposing to conduct a Subcontractor Training Program as a means to increase LEED awareness among subcontracts active on site. This training program will consist an orientation session and bi-monthly workshops to educate the labor force about LEED and the importance of sustainable construction practices.
   Ruling
   The development and implementation of a LEED training program for subcontractors will not qualify for achievement of an innovation credit. While there is clearly an important value in educating the subcontractors working on a LEED project, team education and integrated design are standard for a LEED project. Such education efforts should be best practice and can be incorporated into weekly project meetings. Likewise, educating subcontractors about issues for which they have contractual obligations does not qualify for an innovation credit (LEED ID CIR, 3/2/2004)."

Figure 3.16: Unsuccessful attempt for the Innovation and Design credit

In order to achieve the ID credits through such efforts, the project team needs to plan the strategies and involve its members from project inception. In such a case, greater responsibility would rest on the design and construction team, if the project has to serve as an exemplification of green efforts and stringent adherence during project execution may be required. In both the cases described above, the constructor's contribution can be central in achieving the Innovation and Design credits. Figure 3.17 illustrates a constructor's contribution in achieving credits in the ID category.

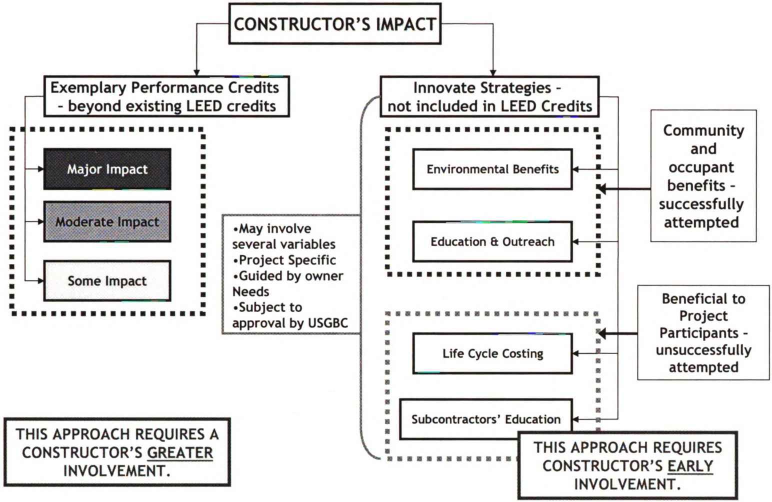


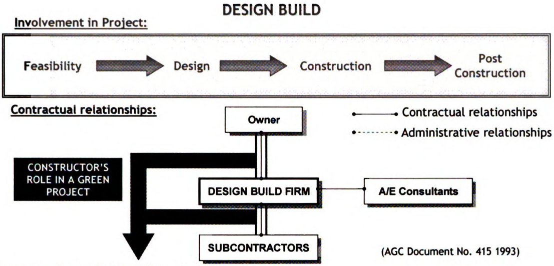
Figure 3.17: Constructor's role in achieving Innovation and Design Credits

3.7 Project delivery methods for Green Projects

Based on the impacts identified in the Project Phase and LEED®-NC Credit Impact Matrices, discussed in the previous sections this section presents a constructor's role in different project delivery methods. In this section, the Design Build contractual method is discussed while other project delivery methods are included in the report titled "Impact of LEED®-NC Projects on the Construction Industry" developed as a part the Environmental Research Initiative, Environmental Science and Policy Program.

3.7.1 Design Build

This contractual method is most favorable for a green project as it helps in involving all project participants early in the project. Figure 3.18 illustrates the design build contractual method for a green project and a constructor's role in it. A constructor's involvement in this method may vary from project initiation or during the feasibility phase. In addition, the constructor is more closely involved in the design phase of the project, as compared to other delivery systems.



- May participate in feasibility studies
- Assists the owner in site selection
- Develops a design based on sustainable design and construction practices
- Provides conceptual estimates
- Participates in material selection process
- Provides input on attempted LEED credits, strategies to achieve them and credit synergies
- Utilizes input of MEP subcontractors during the energy modeling and commissioning phases
- Involves subcontractors in HVAC system design through constructability reviews
- Educates subcontractors about the project's green goals (such as CWM & IAQ plans)
- Coordinates subcontractors for LEED compliance during field operations

Figure 3.18: Constructor's role in Design Build delivery method

3.8 Summary

The credit-by-credit analysis in the form of LEED®-NC credit impact matrix is a vital tool that can help constructors in understanding the LEED®-NC credits and their role in LEED® projects. This is supplemented with the role and responsibilities of constructors in LEED®-NC projects under different project delivery methods. This chapter presented the Project Phase and LEED®-NC credit Impact Matrices developed. The researcher has defined the intent of creating these matrices, their structure, and organization with examples. These matrices include the information collected from case study projects and feedback obtained from the IAG and form the nucleus of this research and the subsequent chapters build on these outputs.

CHAPTER FOUR

LEED®-NC IMPACT DATABASE QUERY APPLICATION

4.1 Introduction

This chapter focuses on the architecture and development of the LEED®-NC Impact Database Query Application. The objective of creating the database is to provide the constructors with a tool, which can assist them in navigating the LEED®-NC Credit Impact Matrix and ascertain their role and contribution in a LEED® project. The subsequent sections outline the basic architecture of the database and its development from the LEED®-NC Credit Impact Matrix. In addition, the chapter includes an example to illustrate the application of this database query system.

4.2 Database Structure and Design

The LEED®-NC Impact database is a relational database, which works on the Microsoft Office© Access platform. The database query system was developed in a two-step process. T he fi rst step was comprised of creating the conceptual model of the database, establishing the relationship between different database entities, and developing its basic architecture. The second step involved creation of the physical model for information retrieval and representation. This step was central in developing the user interface and streamlining the process of information retrieval through queries. These two steps of conceptual database design and physical model development are elaborated in the subsequent sections.

4.2.1 Conceptual Database Design

The conceptual design of the database is based on the LEED®-NC credit impact matrix developed in Chapter 3. A relational database consists of entities which store the data in the form of values, and are related to each other through relationships (such as "one-to-one", "one-to-many" and "many-to-many"). These relationships are based on unique values in each of the entities. In a relational database, the entities are the tables that act as main data storage units. The purpose of the relationships is to facilitate information retrieval from these data storage units based on predefined queries.

In the LEED®-NC credit impact database, two types of tables were created; the "Impact Level" table and the CM function tables. The Impact level table is the main table which stores the information for each LEED® credit. The Impact level table contains information such as LEED® credit, LEED® category, CM function, and the Impact level. This information is related to the second table, which contains data specific to each CM function (Estimation, Scheduling, Project Administration and Documentation) discussed in Chapter 3. The CM function tables contain data such as Discussion Point ID, Impact ID, LEED® credit, LEED® category, and Discussion Points and Examples. All LEED® credits are listed in the Impact Level table and related to the relevant CM function table. The CM function tables include the impacts for the all the LEED®-NC credits in the form of Discussion Points and Examples/Explanation. Thus, each CM function table contains the discussion points for all LEED®-NC credits based on different levels of impact (major impact, moderate impact, and some impact) of these credits on construction project management practices.

The entity relationship (ER) diagram shown in Figure 4.1 illustrates the Impact Level, the CM function tables, and the relationship between them. The unique identifier in this table is the Impact ID, through which each LEED®-NC credit is connected to different CM functions. The Impact ID is a special value assigned to each LEED®-NC credit and appears in different tables, as the main connector in the database. As evident in Figure 4.1, the Impact Level table is related to the CM function tables with a one-to-many relationship shown with symbols 1 and ∞ on the relationship lines between the tables. This relationship demonstrates that one LEED®-NC credit may have many impacts on any of the six identified CM functions, and these impacts are listed as different discussion points under each CM function.

The above discussion covered the organization and storage of information in the database, and the subsequent sections cover its functional aspects.

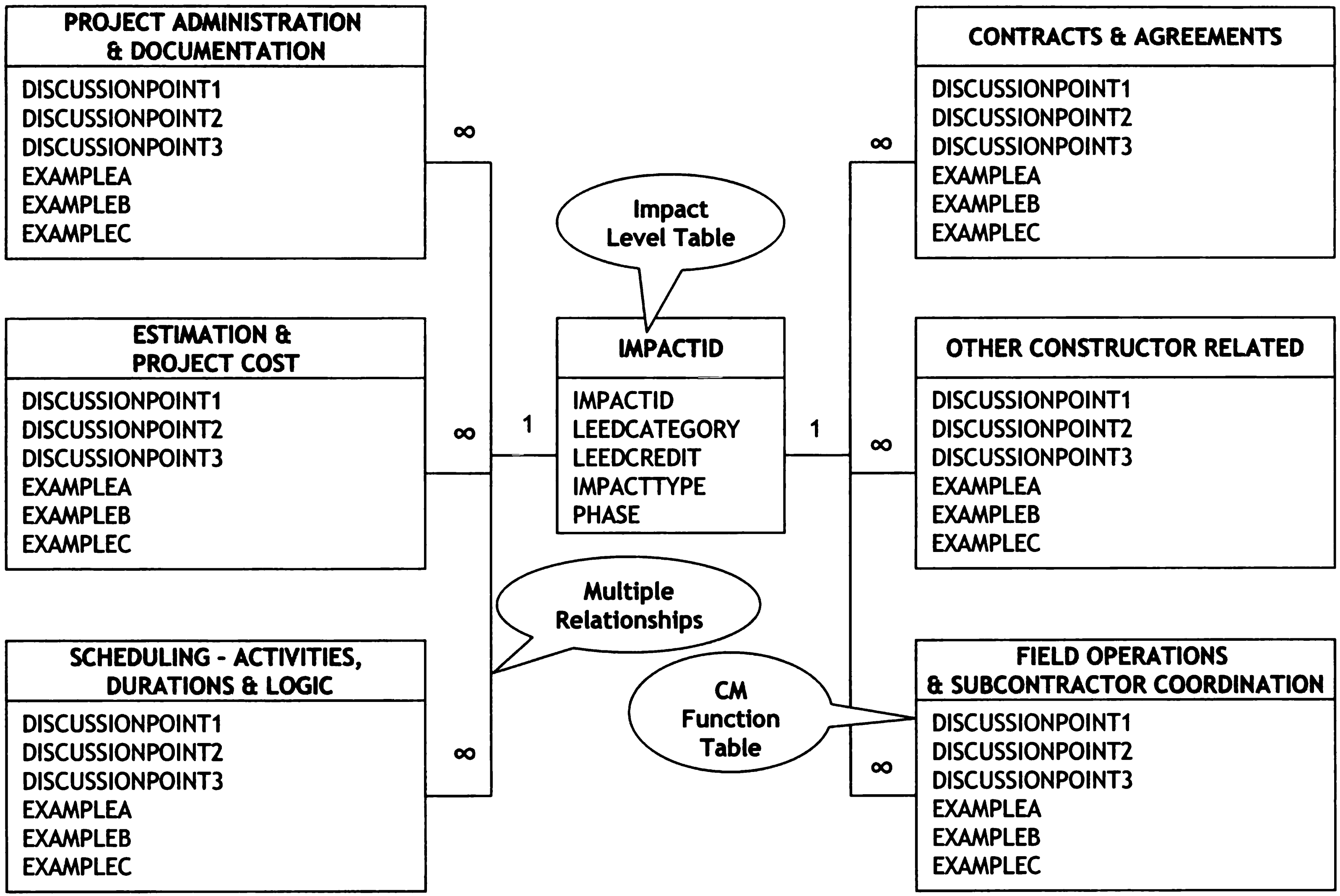


Figure 4.1: Entity Relationship Diagram – LEED®-NC Impact Database

4.2.2 Database Physical Model

After creating the database entities and establishing the relationships, the next step was to create the queries in order to retrieve information stored in the database and create the user interface to access the information. After creating the database structure, the queries required to access the database were developed.

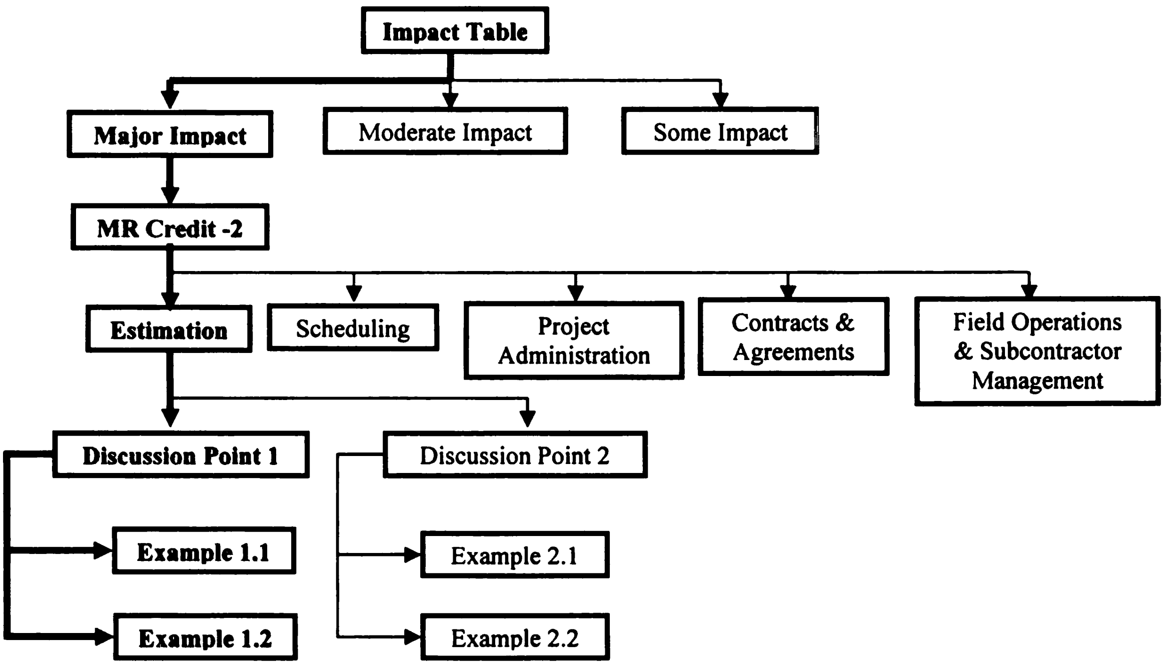


Figure 4.2: Query mechanism for retrieving estimation impacts for a sample LEED®-NC Credit (MR C-2)

The queries were developed for the sorting and retrieving of information for a particular LEED®-NC credit and that credit's impact on a CM function. For instance, in order to view the impact of Materials and Resources Credit – 2: Construction Waste Management Plan during construction on the Estimation CM function, the query shown in Figure – 4.2 would function. The query collects the Impact ID for MR credit-2, which is a major impact credit from the impact level table, takes the impact ID to the Estimation table and matches the ID. It then retrieves the impacts identified under the Estimation CM function and presents the discussion points and examples to the user. The physical model of the database was developed with the intention that new CM functions and LEED® credits could be incorporated, without altering the existing database structure.

4.2.3 User Interface

The main window of the database acts as a navigation menu for the users and remains active whenever the database is accessed. From this main menu, the user has three options to select a specific LEED® category to view the impacts, view the references for the database, and exit the database. The LEED®-NC credits are color-coded based on their level of impact on the CM functions. On selecting a particular LEED®-NC credit, a new window appears that lists the CM functions.

Selecting a particular CM function leads the user to a new window that contains the discussion points and examples for that function. In the following section, an example for a major impact credit, MR Credit-2 Construction Waste Management, and a moderate impact credit, ID Credit -1, is discussed.

4.3 Illustrative example of Major and Moderate Impact Credit

In order to demonstrate how the database functions, this section illustrates the process of initiating the database application and retrieving impacts. Two levels of impact are discussed to effectively exemplify the constructor's role in the green building process and these include a major impact credit and a moderate impact credit.

4.3.1 Major Impact Credit (MR Credit 2 – Construction Waste Management)

The database is initiated by opening the file in MS© Access. The main window will appear on start up and remain active until the database is closed. Once the main database window appears as shown in Figure 4.3, the subsequent steps illustrate the process of retrieving impacts on constructor's activities for MR Credit 2.

1. In the main database window, the LEED®-NC credits appear as shown in Figure 4.3. This active list is connected to the MS© Access forms, which the users eventually see and can print. The credits are organized based on their level of impact on the CM functions. In addition, the two command buttons in the bottom corner of this window function as described mentioned below:
    a. The References command button links the main window to the references used for discussion points.
    b. To exit the database the second command button, Exit Database is used.
2. From the Materials and Resources category the user can select the "MR- Credit -2: Construction Waste Management" button as shown in Figure 4.3. This will lead to the next window, which displays the CM functions for the selected LEED®-NC credit, as shown in Figure 4.4. From this window, the user selects the "Project Administration and Documentation" function. Similarly, all LEED®-NC credits have been analyzed for other CM functions as identified in Chapter 3.

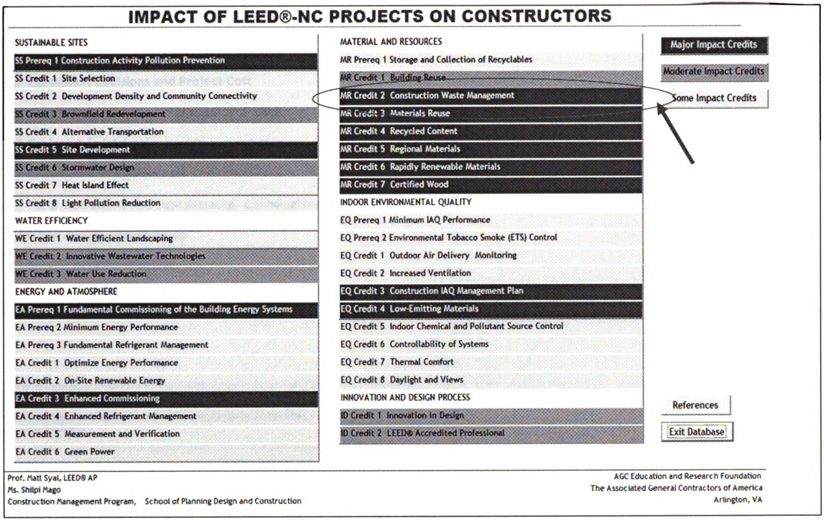


Figure 4.3: Main database window

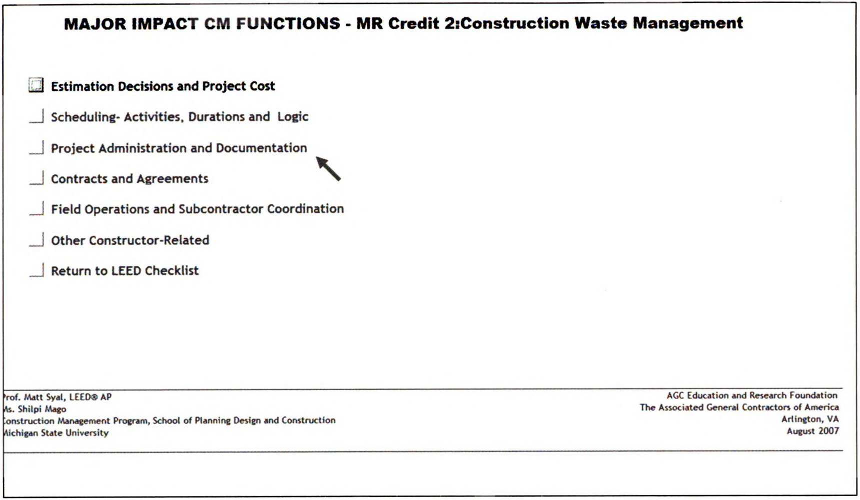


Figure 4.4: MR Credit 2-Construction Waste Management – CM Functions

3. On selecting the “Project Administration and Documentation” CM Function, the discussion points and examples appear as shown in Figure 4.5. The discussion points are followed by examples/ explanations that supplement the discussion. The navigation buttons at the bottom of the window help the user to navigate to the next and previous discussion points.

In addition, all those examples that contain pictures, documents, and/or figures appear as command buttons as shown in Figure 4.6. On selecting these command buttons, the linked documents, pictures, and figures open as PDF documents in a new window. As shown in Figure 4.6, the selection of “Sample Construction Waste Management Plan” leads to the PDF document shown in Figure 4.7. After viewing these documents the user may close these PDF files and continue working in MS® Access window.

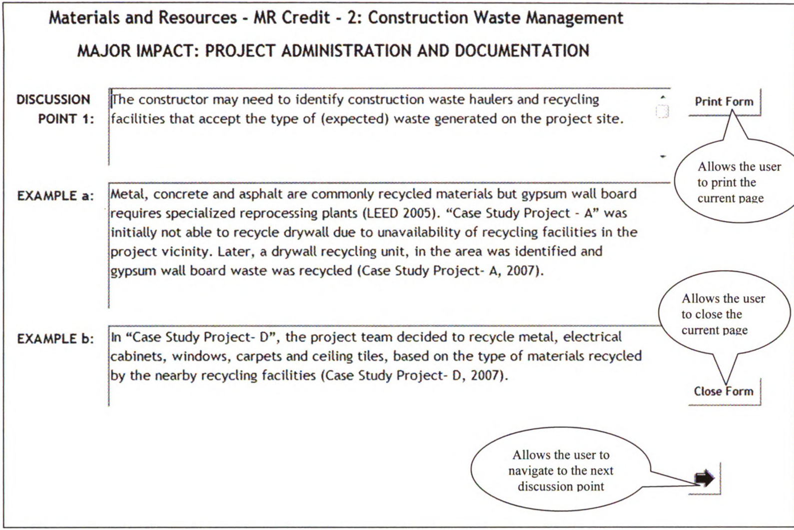


Figure 4.5: MR Credit 2- Project Administration and Documentation

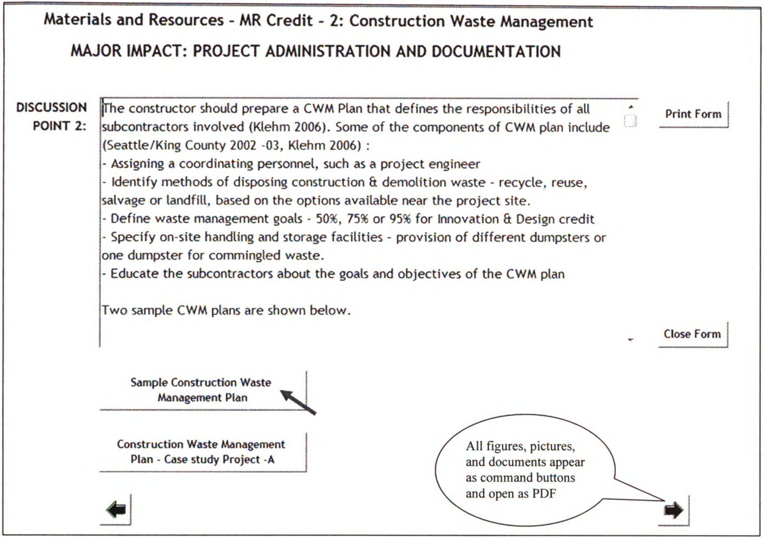
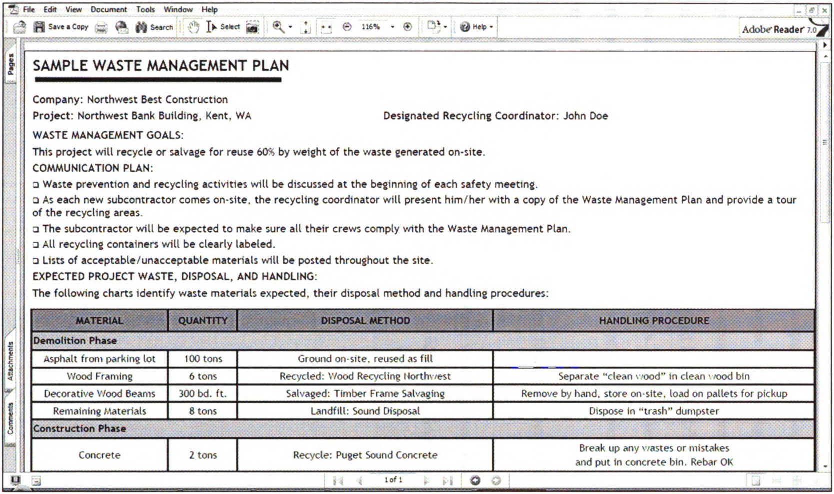


Figure 4.6: MR Credit 2 - Command buttons for linked documents



SAMPLE WASTE MANAGEMENT PLAN

Company: Northwest Best Construction

Project: Northwest Bank Building, Kent, WA — Designated Recycling Coordinator: John Doe

WASTE MANAGEMENT GOALS:

This project will recycle or salvage for reuse 60% by weight of the waste generated on-site.

COMMUNICATION PLAN:

- Waste prevention and recycling activities will be discussed at the beginning of each safety meeting.
- As each new subcontractor comes on-site, the recycling coordinator will present him/her with a copy of the Waste Management Plan and provide a tour of the recycling areas.
- The subcontractor will be expected to make sure all their crews comply with the Waste Management Plan.
- All recycling containers will be clearly labeled.
- Lists of acceptable/unacceptable materials will be posted throughout the site.

EXPECTED PROJECT WASTE, DISPOSAL, AND HANDLING:

The following charts identify waste materials expected, their disposal method and handling procedures:

MATERIAL	QUANTITY	DISPOSAL METHOD	HANDLING PROCEDURE
Demolition Phase			
Asphalt from parking lot	100 tons	Ground on-site, reused as fill	
Wood Framing	6 tons	Recycled: Wood Recycling Northwest	Separate "clean wood" in clean wood bin
Decorative Wood Beams	300 bd. ft.	Salvaged: Timber Frame Salvaging	Remove by hand, store on-site, load on pallets for pickup
Remaining Materials	8 tons	Landfill: Sound Disposal	Dispose in "trash" dumpster
Construction Phase			
Concrete	2 tons	Recycle: Puget Sound Concrete	Break up any wastes or mistakes and put in concrete bin. Rebar OK

Figure 4.7: MR Credit 2 – Linked documents open as PDF documents

4.3.2 Moderate Impact Credit ID Credit 1-Innovation in Design

The Innovation and Design (ID) category is unique as it provides an opportunity for the project team to utilize a constructor's expertise in achieving the green building objectives. Most of the credits that qualify for exemplary performance, under the ID credit, form part of the constructor's role as outlined in the LEED®-NC Impact Matrix. Thus, in order to achieve ID credits, constructor's early involvement and increased participation in the project is imperative. Therefore, the ID category is used as an example for moderate impact credits.

As these credits are not described in the typical format of other LEED® credits, the discussion points for these are presented differently.

1. After initiating the database, the main database window appears. To view the ID impacts, the user can make a selection from the credits, as shown in Figure 4.8.

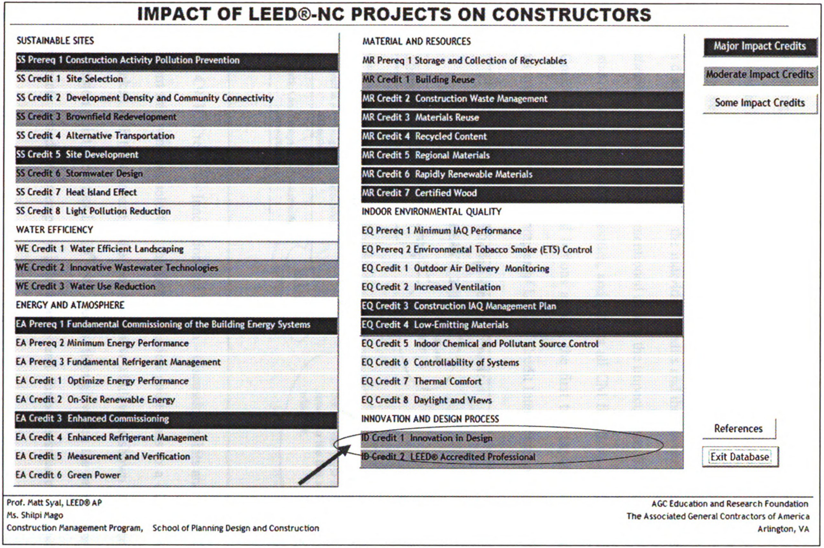


Figure 4.8: Main database window

2. On selecting the ID Credit -1, the Innovation and Design discussion window appears as shown in Figure 4.9. This credit does not have the CM functions that are discussed in the above example. Moreover, the exemplary performance of LEED® credits has been discussed in detail under the individual credits and their overall impact has been reiterated in this category. As mentioned above, the impact of the ID category is more holistic on a constructor's activities, and affects all CM functions. Therefore, in the ID Credit – 1, four command buttons appear, the first two explain the discussion points and the next two are examples of LEED® Credit Interpretation Requests (CIR).

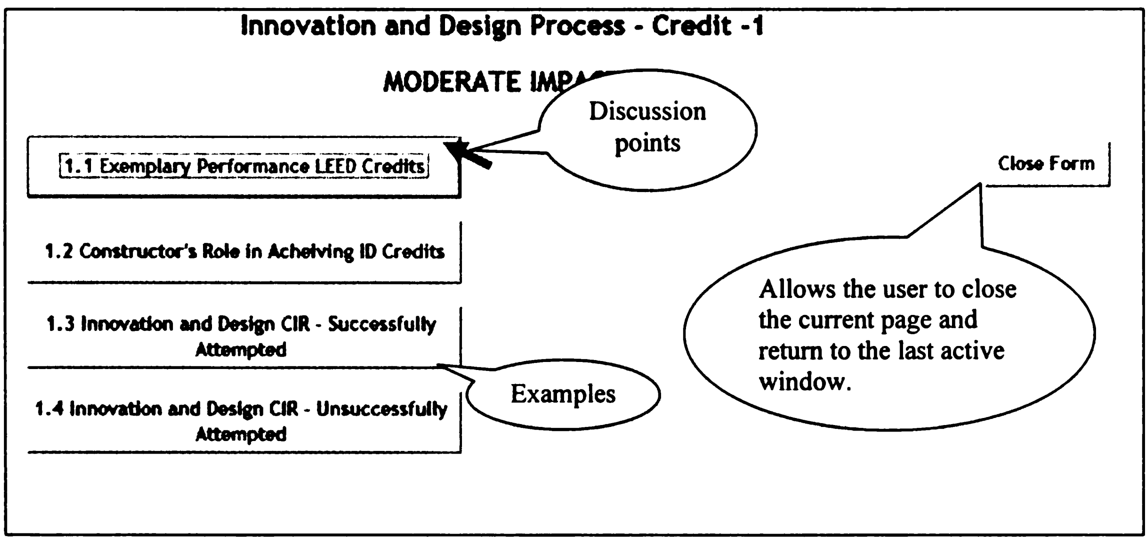


Figure 4.9: ID Credit-1 – Innovation and Design – discussion points and examples

From this window, selecting the first discussion point leads to a PDF document which is linked with the database and appears in a new window, as shown in Figure 4.10. This discussion point identifies LEED®-NC credits, through which the project team can achieve points based on exemplary performance and further reinforces the need to involve the constructor early in the project. From this window, the user can exit the PDF document and return to the ID credit window.

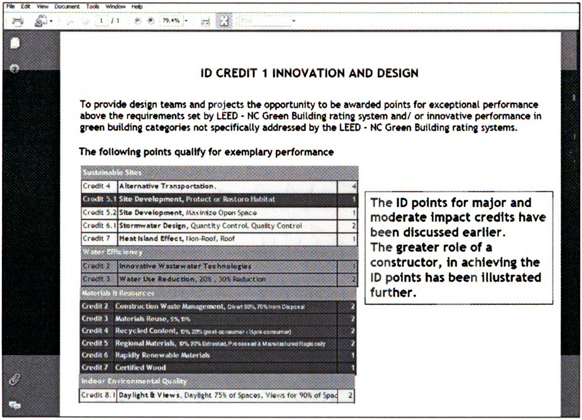


Figure 4.10: ID Credit -1 – Linked documents from the main ID Credit window

Similarly, the other three command buttons in the ID credit window are linked to the respective PDF documents as shown in Figure 4.11-4.16.

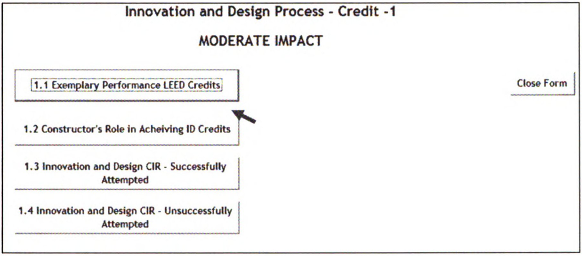


Figure 4.11: ID Credit-1 – Innovation and Design – second discussion points

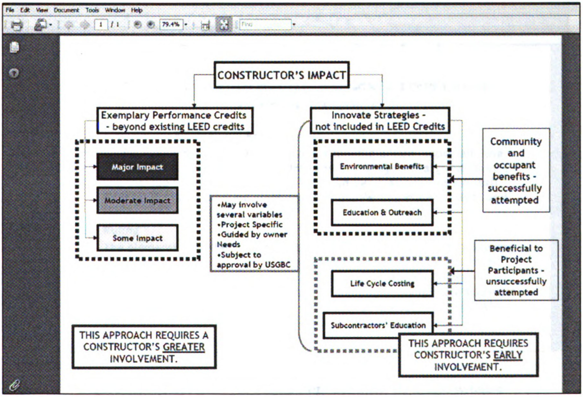


Figure 4.12: Second discussion points linked from the main ID credit window

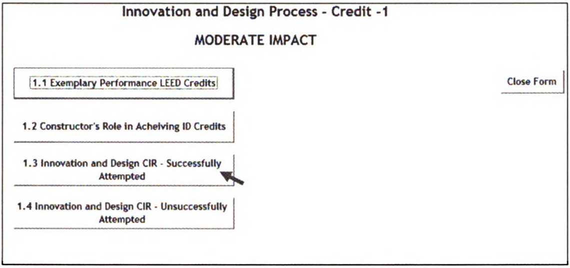
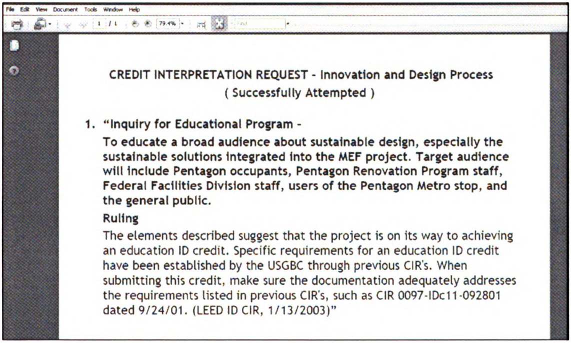


Figure 4.13: ID Credit-1 – Innovation and Design – first example



CREDIT INTERPRETATION REQUEST - Innovation and Design Process
(Successfully Attempted)

1. **"Inquiry for Educational Program -**

   To educate a broad audience about sustainable design, especially the sustainable solutions integrated into the MEF project. Target audience will include Pentagon occupants, Pentagon Renovation Program staff, Federal Facilities Division staff, users of the Pentagon Metro stop, and the general public.

   Ruling

   The elements described suggest that the project is on its way to achieving an education ID credit. Specific requirements for an education ID credit have been established by the USGBC through previous CIR's. When submitting this credit, make sure the documentation adequately addresses the requirements listed in previous CIR's, such as CIR 0097-IDc11-092801 dated 9/24/01. (LEED ID CIR, 1/13/2003)"

Figure 4.14: First example linked from the main ID credit window

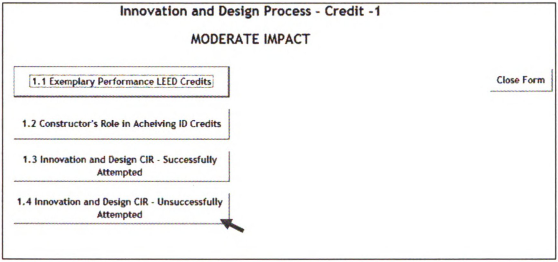
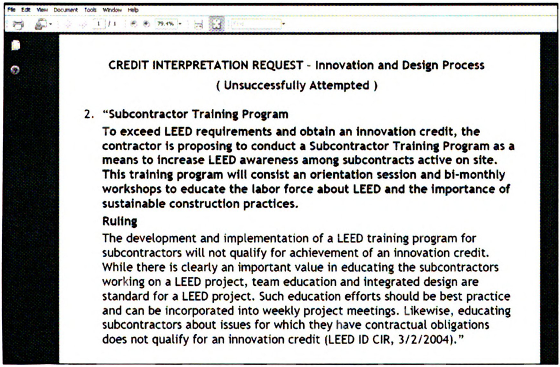


Figure 4.15: ID Credit-1 – Innovation and Design – second example



CREDIT INTERPRETATION REQUEST - Innovation and Design Process

(Unsuccessfully Attempted)

2. **"Subcontractor Training Program**

   To exceed LEED requirements and obtain an innovation credit, the contractor is proposing to conduct a Subcontractor Training Program as a means to increase LEED awareness among subcontracts active on site. This training program will consist an orientation session and bi-monthly workshops to educate the labor force about LEED and the importance of sustainable construction practices.

   Ruling

   The development and implementation of a LEED training program for subcontractors will not qualify for achievement of an innovation credit. While there is clearly an important value in educating the subcontractors working on a LEED project, team education and integrated design are standard for a LEED project. Such education efforts should be best practice and can be incorporated into weekly project meetings. Likewise, educating subcontractors about issues for which they have contractual obligations does not qualify for an innovation credit (LEED ID CIR, 3/2/2004)."

Figure 4.16: First example linked from the main ID credit window

The LEED®-NC impact database was sent to the IAG for feedback on user interface and ease of accessing the information stored in the database. The comments received from the IAG were incorporated in the final database.

4.4 Summary

A database query application tool was developed to access the impact of LEED®-NC projects on constructors. The database entities were developed from the components of the LEED®-NC credit impact matrix. This chapter presented the design and development process of the LEED®-NC Impact database. As an extension of database design, the discussion also entailed the user interface and ease of accessing the information. In addition, to supplement the user's understanding, the researcher has illustrated how to access the discussion points and examples for major and moderate impact credits. The development of the database is the last phase in identifying the impacts of LEED®-NC projects on construction management practices.

CHAPTER FIVE

PROCESS MODEL FOR IMPACT ASSESSMENT OF GREEN BUILDING PROGRAMS

5.1 Introduction

This chapter entails a detailed discussion of the process used to develop the research outputs. The researcher has attempted to model this process and make it generic for analyzing the impacts of other green building programs on project management practices of different sectors in the built environment, by other researchers. The process model developed in this research can be applied to determine the impacts on practices of builders, developers, renovation contractors, subcontractors, facilities managers, etc. In the following sections, the word "constructor" has been used to refer to these construction industry stakeholders.

5.2 Process Steps for Impact Assessment of Green Building Programs

The process model for Impact Assessment of Green Building Programs consists of four process milestone steps of 1) Review Literature; 2) Develop Project Phase Assessment, 3) Develop Green Building Impact Assessment, and 4) Develop Impact Analysis application tool as shown in Figure 5.1. In the following sections, the function and sub steps within these milestone steps have been discussed, along with the activities that should be conducted in order to achieve these process steps, as shown in Figure 5.2. The discussion in the subsequent sections shows parts of the process model developed.

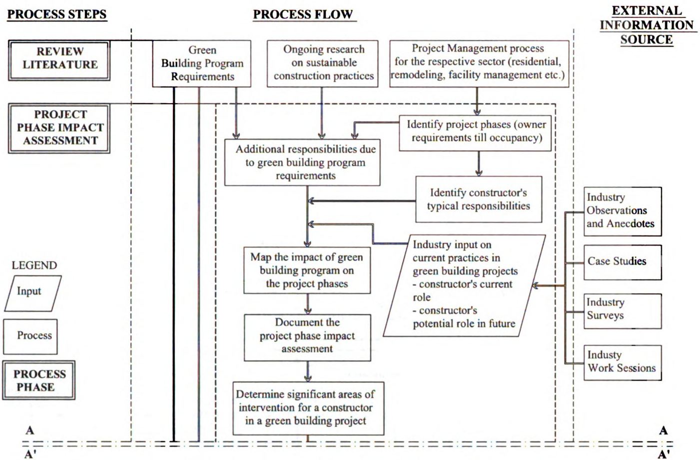


Figure 5.1: Process Model for Impact Assessment of Green Building Guidelines

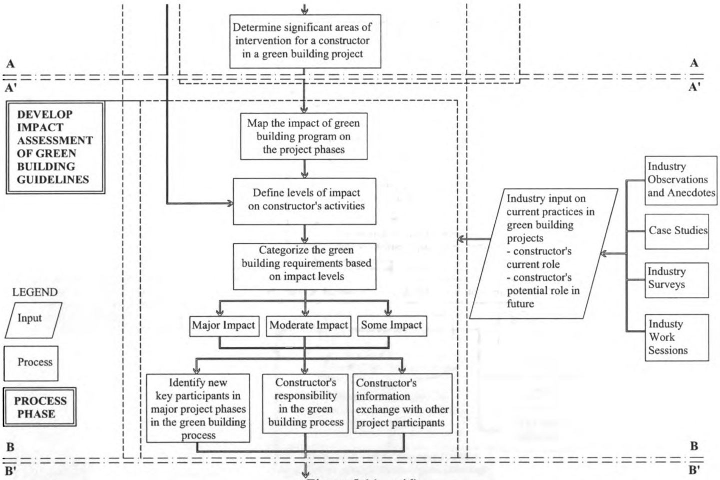


Figure 5.1(cont'd)

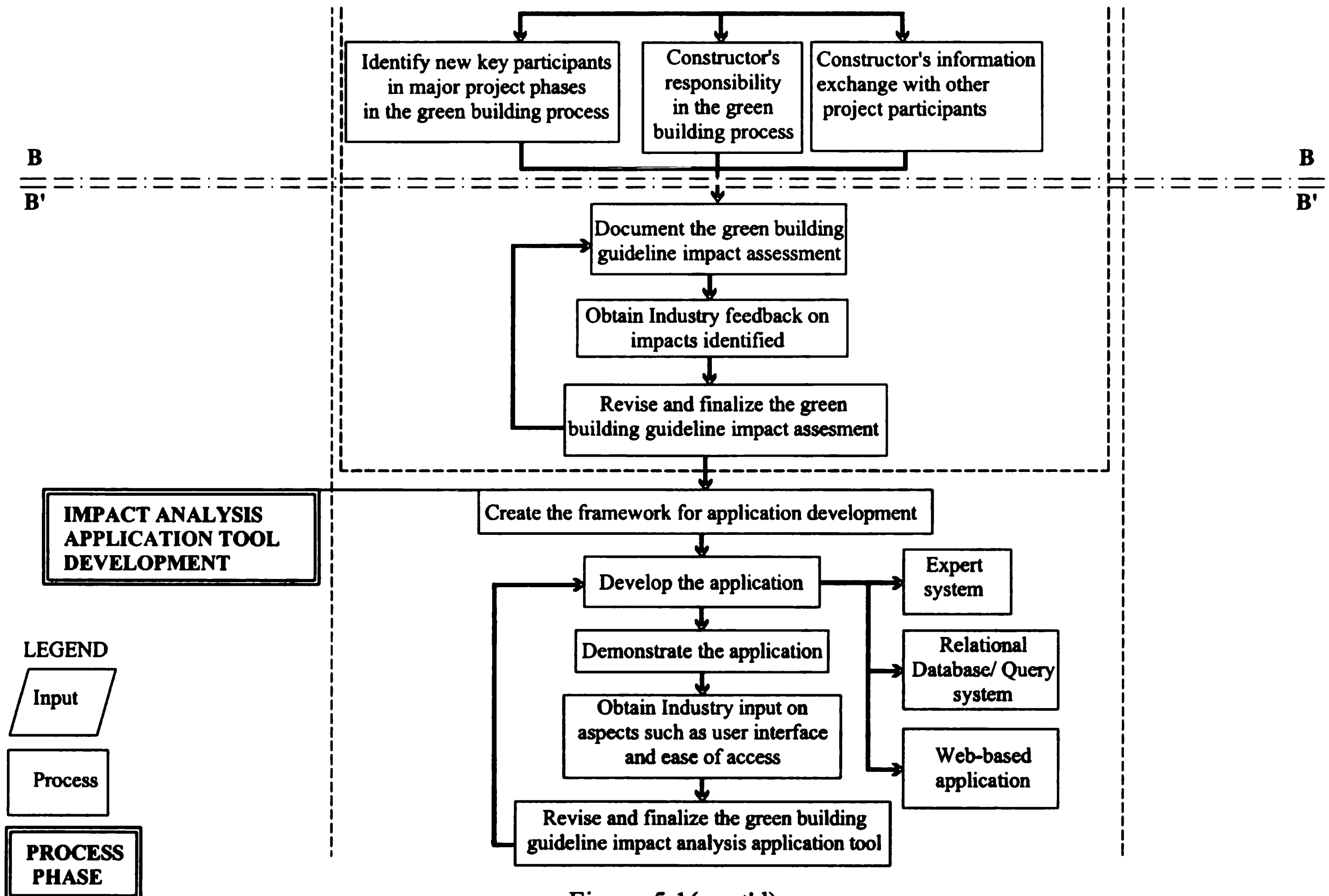


Figure 5.1(cont'd)

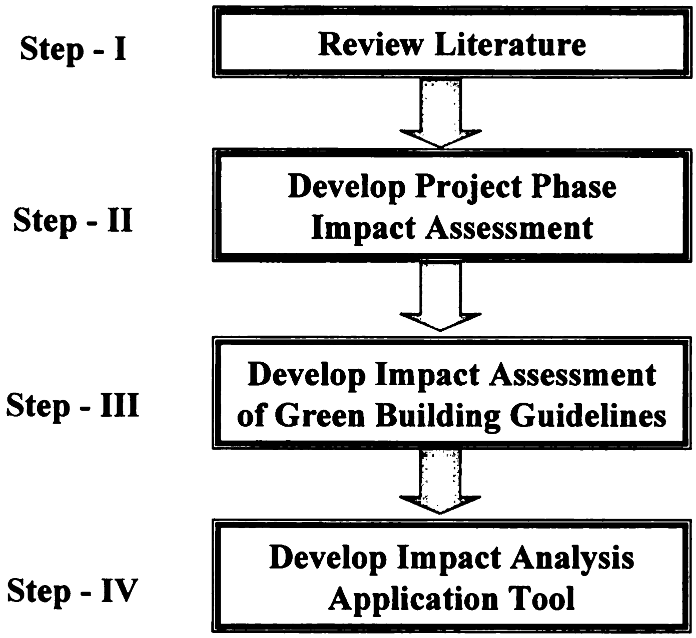


Figure 5.2 – Green Building Impact Assessment Process

5.2.1 Review Literature

The first step in initiating the process of impact assessment of green building programs is to identify and review pertinent literature. Three distinctive sections of literature have been identified as shown in Figure 5.3. However, based on the nature of the construction sector for which the impacts are being identified, more sections may be included. The three sections specified in the process model are:

1. Green building program requirements
2. Ongoing research on sustainable construction practices
3. Project management process for the respective sector.

Review of the green building program is essential for the researcher to gain an understanding of the technical requirements of the green building rating system.

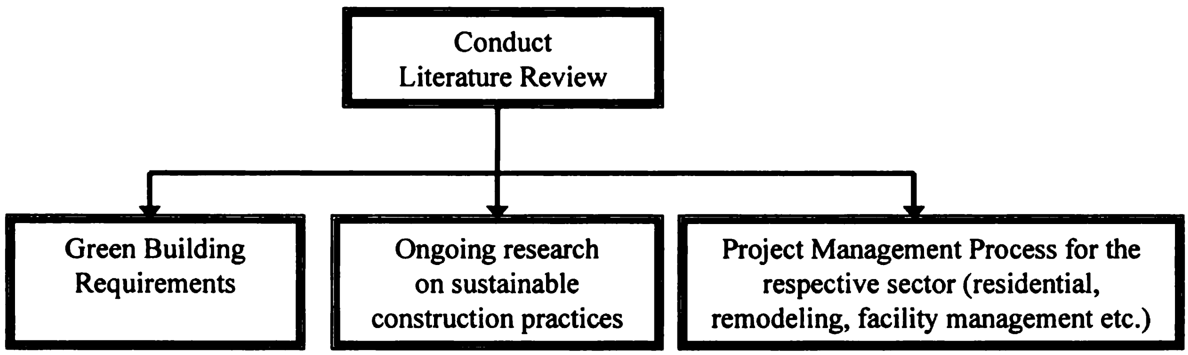


Figure 5.3: Literature Review Sections

The emphasis on the ongoing research efforts will bring in the perspective of current research practices in the field of sustainable construction and supplement the impact analysis. The last section of the literature review focuses on the project management practices of the construction sector under focus. In order to analyze the impacts of green building program requirements, the researcher's understanding of project management requirements will be an imperative step, which will provide the researcher with a base knowledge, and help to compare the additional activities required in a green building project.

5.2.2 Project Phase Impact Assessment

After reviewing the background literature, the next step is to assess the project phase impacts. This process step entails six sub steps depicted in Figure 5.4. One of the main outcomes of understanding the project management aspects of a particular construction sector is to identify the project phases involved and, for each project phase, identify the typical responsibilities of a constructor. This step would primarily flow from the project management practices of that particular construction sector. After identifying the typical responsibilities of the constructor, the researcher will derive additional responsibilities of a constructor in context of the green building program, based on its technical requirements and other research efforts on sustainable construction practices. The researcher needs to analyze the gap between the constructor's typical and additional responsibilities, and supplement the analysis with industry input. The role of industry input during this phase is significant, as it will equip the researcher with observations made by industry professionals, case studies, industry surveys, and work sessions, as shown in Figure 5.4.

Once the constructors' additional responsibilities have been identified, the researcher can now map the impacts throughout different phases of design and construction process of green buildings and subsequently document these impacts. The project phase impact assessment will then act as an input for the next process step of assessing the impact of green building guidelines. Between these two process steps, however, is a transition step that was introduced to assimilate the project phase assessment and identify the components of impact assessment of green building guidelines. The function of this transition step was to determine those aspects and/or areas in a green building project, where a constructor's role may be significant, based on the impact assessment done for project phases. These intervention areas will be further used to examine a constructor's role in complying with the green building requirements in the next process step.

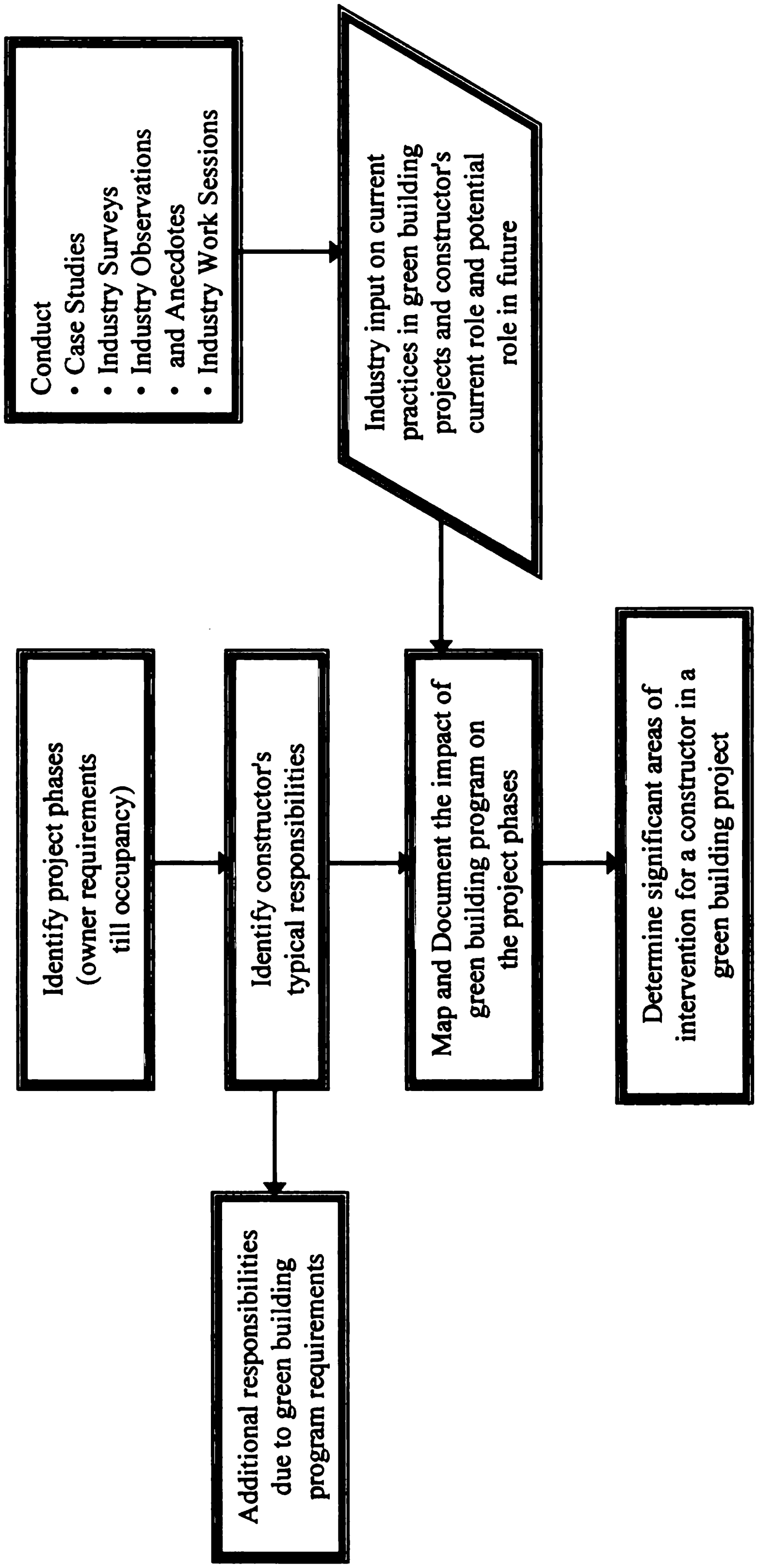


Figure 5.4 - Project Phase Impact Assessment

5.2.3 Impact Assessment of Green Building Guidelines

The output of the last process step will provide the researcher with significant areas of intervention for a constructor in a green building process, which will be used as type of impacts in the third process step. In this research, the significant phases were estimation, scheduling, project administration, etc. In the analysis of the project phase impacts, it was observed that a constructor is closely involved in the project in these phases and some of the major LEED® credits are dependent or achieved in these phases. These observations reinforced a constructor's significant role in a green building process and the LEED® certification and their detailed discussed is presented in Chapter 3.

After determining the impact types on a constructor's activities, the researcher will categorise the impacts under this typology, for all green building rating parameters. In this research, the parameters were the LEED®-NC credits and, for each credit, impacts were categorized under Estimation Decisions & Project Cost, Scheduling- Activities, Durations & Logic, Project Administration and Documentation, Contracts and Agreements, and Field Operations and Subcontractor Coordination. Further, the researcher will identify impact levels in order to classify the green building parameters. The basis of this classification is a function of the research objectives and its overall goal. For this research, the classification was based on the extent of constructor's contribution and involvement in achieving a particular LEED®-NC credit and therefore three impact levels were identified, namely major, moderate and some. These impact levels were created in order to help the constructors to effectively understand their role in a green building process and accordingly plan for it during the preconstruction and project planning phases.

The Major impact LEED®-NC credits were those in which a constructor will be directly involved for achieving that credit and the documentation involved will be contingent on the construction phase activities. For instance, both MR-Credit -2 – Construction Waste Management and EQ –Credit-3 –IAQ Management require additional activities by the constructor and the constructor mostly submits the documentation (LEED® IAG Session 2006). The moderate credits were those that had immense potential for obtaining constructor's input through their early involvement in order to streamline the green building process. A pertinent example of moderate credits is the Innovation and Design category, which has been discussed in detail in Chapter 3. Some impact credits were those in which the constructor's involvement was the least and the credits were mostly dependent on the design of the project. The sub steps of Impact Assessment of Green Building Guidelines are illustrated in Figure 5.5.

In order to determine the impacts on a constructor's activities, the researcher will further analyze the changes in a constructor's typical responsibilities in a green building process and the green building guidelines. Three important aspects have been identified, which the researcher will use to establish the impacts. These are

- Identify new key participants in the green building process
- Constructor's responsibility in the green building process
- Constructor's information exchange with other project participants in the green building process

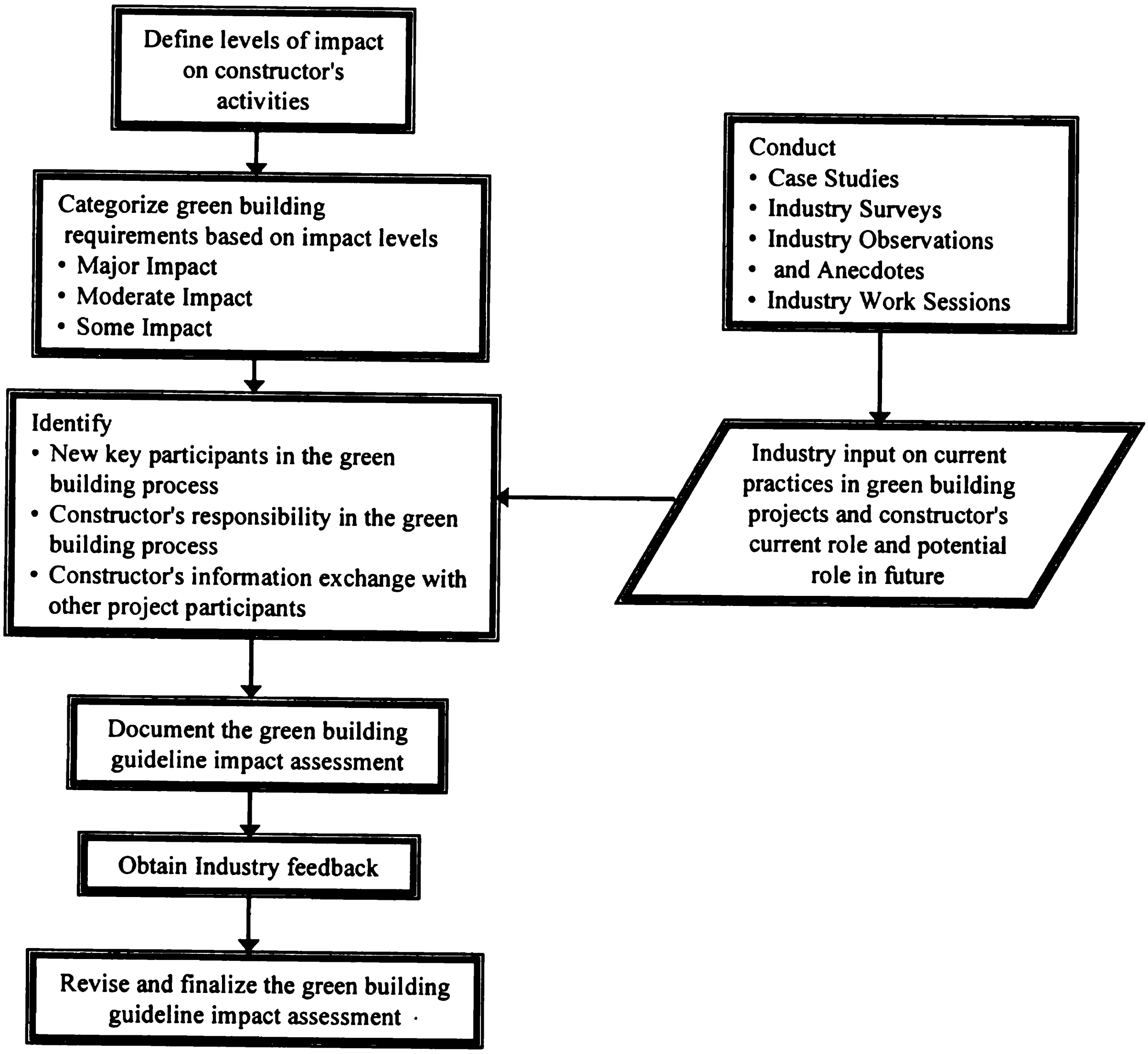


Figure 5.5: Impact Assessment of Green Building Guidelines

The impacts identified by the researcher will be further supplemented by the industry input through case studies, industry surveys, and observations made by industry professionals and industry work sessions. The researcher will then present the findings in an industry work session to obtain feedback and revise the impacts based on the feedback. In this research, case studies, industry surveys, observations made by industry professionals were used to supplement the researcher's findings and the impact assessment of green building guidelines was presented to an Industry Advisory Group (IAG), comprised of constructors, facility managers, architects, and commissioning agents. This was as an exceptional platform for knowledge sharing and the feedback obtained from IAG members was incorporated in the assessment.

5.2.4 Impact Analysis Application Tool Development

The fourth process step entails the development of an application tool to disseminate the impact assessment of green building guidelines as shown in Figure 5.6. In this process step, the researcher will first need to determine the type of application required. Based on the type of application to be developed, such as an Expert System, Web – Based Application or a relational database/query system, the researcher will create the framework for developing the application, in conjunction with structure of the impact assessment of green building guidelines. After developing the framework for the application, the researcher will then develop the application.

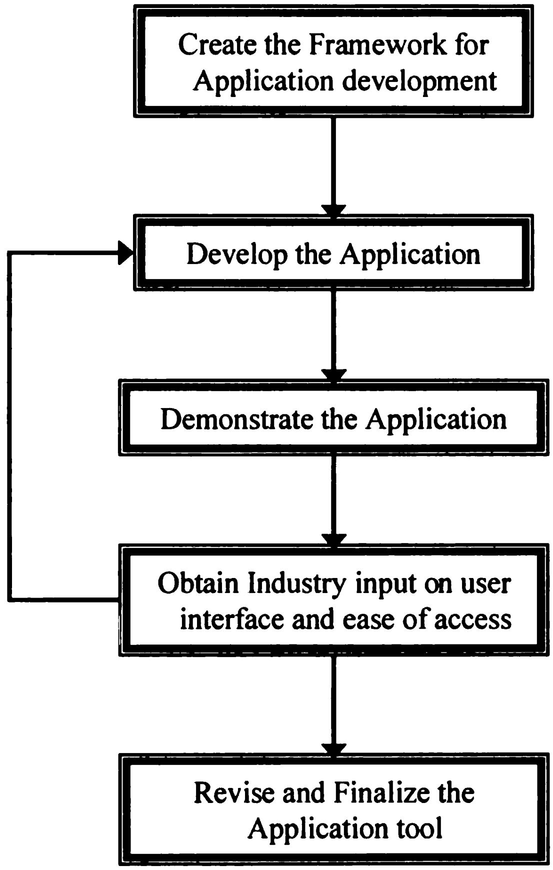


Figure 5.6: Impact Analysis Development Tool

In this research, a relational database-query system was developed that laid out a constructor's responsibilities under all LEED®-NC credits, consistent with the impact levels and types described above. A detailed description of database development and format has been presented in Chapter 4.

5.3 Application of the Process Model

The previous sections covered the process model for analyzing the impact of green building programs on constructor's activities and practices. In this research, LEED®-NC was taken as a reference and its impacts were identified on construction project management practices. In order to demonstrate the application of the process model, the researcher has illustrated an example of LEED®-Homes (H) (LEED-H 2007), MR Credit 2 – Environmentally Preferable Products and the four process steps explained above have been described in context of LEED®–H.

5.3.1 LEED-H: MR Credit 2 – Environmentally Preferable Products

The following illustration is to identify the impact of LEED®- H requirements for MR Credit 2 – Environmentally Preferable Products on constructors' activities. The intent of this credit is to promote the use of environmentally preferable products, which are extracted, processed, and manufactured within the region. Further, according to LEED®- H, "an environmentally preferable product refers to products and services that have lesser or reduced effect on human health and the environment, when compared with competing products that serve the same purpose" (LEED®- H 2007).

5.3.1.1 STEP-1: Conduct Literature Review

For this step, two primary sources of information will be LEED®- H requirements and the Residential project management process, as shown in Figure 5.7. In addition, the researcher should explore the current practices in LEED®- H and the home building industry.

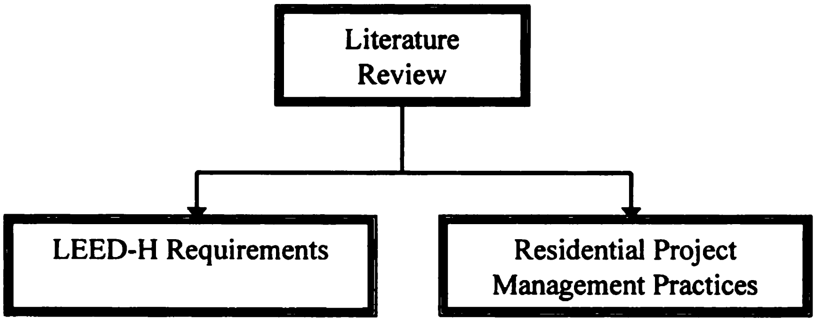


Figure 5.7: Literature Review Components for LEED®- H Illustration

5.3.1.2 STEP-2: Project Phase Impact Assessment

From the literature reviewed, the researcher will identify the typical project phases in a home building process. For the purpose of this illustration, the following phases have been identified – Design Development, Preconstruction, Contracts and Agreements, Project Execution, and Inspection & Closeout.

Under these main project phases, certain sub phases have also been identified as shown in Figure 5.8. The focus of this credit is to increase the use of products that are more environmentally preferred such as Forest Stewardship Council (FSC) certified wood, products with recycled content, materials or products that are reclaimed, materials that are bio-based or derived from agricultural residue and materials that have low VOC content. Another aspect of this credit is promotion of local resources, wherein material procurement from within 500 miles of project location is preferred.

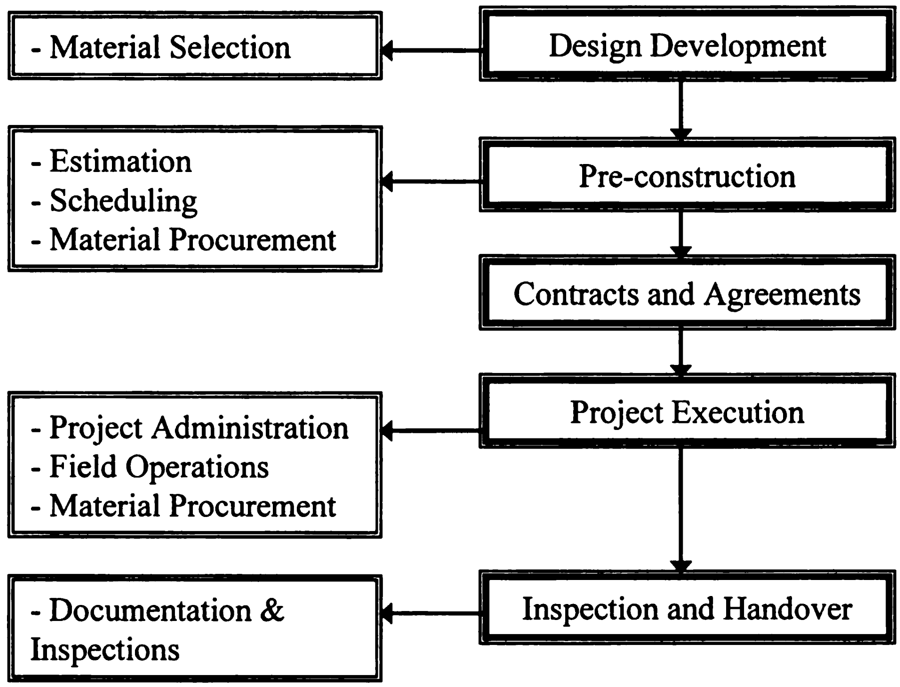


Figure 5.8: Project phases and sub phases for LEED-H Illustration

Thus, in the project phases identified above, a homebuilder's significant role in conjunction with this credit can be seen in the design development, pre-construction, project execution, and inspection and handover phases as shown in Figure 5.8. For the purpose of this illustration, the researcher has identified some impacts in each project phase, as shown in Table 5.1. In case this impact assessment was developed as done in this research, more examples and observations could have been included, based on industry input.

Table 5.1: Project Phase Impact Assessment

PROJECT PHASE	CONSTRUCTOR'S ROLE	REMARKS / RESOURCES
Design Development	1. Constructor will have a major role in material section and preparation of construction specifications.	With experience from past LEED projects, the constructor can help in preparing the initial LEED- H checklist, based on typical floor plans and availability of green materials and suppliers in project vicinity.
Pre-Construction	**Estimation** 1. Cost of green materials may be comparatively higher than typical materials. **Scheduling** 1. Lead – time of green materials may be longer and should be considered in the pre construction phase. **Material Procurement** 1. Availability of green materials in the project vicinity should be explored	
Project Execution	**Project Administration** 1. Lead – time of green materials may be longer and should be considered in the pre construction phase. **Field Operations** 1. Special provision for storage of green materials on site **Material Procurement** 1. Availability of green materials in the project vicinity should be explored	
Inspection & Closeout	The constructor is responsible for submitting the material information sheets received from material suppliers and all other documentation.	

5.3.1.3 STEP-3: Impact Assessment of LEED®- H Requirements

From the project phase impact assessment, the significant areas of constructor's intervention were identified as

- Design Development
- Estimation and Project Cost
- Scheduling
- Project Administration
- Field Operations

These significant areas may vary if the same assessment was conducted for all LEED®-H credits, as certain credits may have impact in other project phases such as Contracts and Agreements. These significant areas will be used as impact types in order to develop the impact of green building guidelines. In addition, MR Credit -2 lies in the category of Major impact credits, as it is evident from the requirements of MR Credit -2, that a constructor's role is significant in achieving it. For this example, the researcher has presented the impacts under the impact types mentioned above, in Table 5.2. These impacts can be further developed with input from case studies, industry surveys and observations made by the industry professionals.

The function of this illustrative example is to depict the process used for assessing the impact of green building requirements on constructors' practices, so that it can be further used by other researchers in order to achieve a similar goal to this research.

Table 5.2: Example LEED®- H, MR Credit 2 - Impact Assessment of Green Building Guidelines
Impact Level – Major

Construction Management Function - DESIGN DEVELOPMENT			
LEED Credit	Discussion Point	Example/ Explanation	Reference
MR-Credit – 2: Environmentally Preferable Products	1. The constructor will be responsible for selecting material specifications during the design phase and coordinate them with the interior designer. Even while preparing different floor plan options, the specifications will have to be matched with the level of LEED rating being achieved.		
Construction Management Function - ESTIMATION AND PROJECT COST			
	1. In addition to the cost of Green materials, which may be higher than typical materials, the constructor should also look into other factors such as cost of transportation and availability of that material within 500 miles of the radius.		
Construction Management Function - SCHEDULING			
	1. In addition to the cost of Green materials, which may be higher than typical materials, the constructor should also look into other factors such as cost of transportation and availability of that material within 500 miles of the radius.		
Construction Management Function - PROJECT ADMINISTRATION			
	1. The constructor will be responsible for collecting and documenting all LEED submittals and obtain the third party accountability forms.		
Construction Management Function - FIELD OPERATIONS			
	1. The constructor will be responsible for storage of green materials on site in case they require any special storage conditions. The field personnel on site will have to ensure that procurement and installation of green material complies with the LEED-H requirements.		

5.3.1.4 STEP 4 - Development of Impact Analysis Application Tool for LEED®- H MR Credit -2

For an illustration of this process step, it will be relevant that the reader refers to the development of the LEED®-NC Impact Database/Query system developed for this research. This process step is dependent on the nature of the research and the type of application to be developed, as the application development steps will vary accordingly.

5.4 Summary

The methodology adopted for this research was captured in a process model that can assist in investigating the impact of green building programs on different construction industry sector. Major project phases and comprehensive steps under these phases were developed. This chapter discussed the development of this process model. This model could be further used by similar researches in order to identify impacts of other green building programs. Different steps undertaken in this research have been presented with examples to render a better understanding. In addition, the researcher has presented an example illustrating the application of this process model.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

6.1 Overview

This chapter presents a summary of the research conducted and several observations and conclusions. The discussion progresses with the summary of research objectives, description of project phase and LEED®-NC impact matrices, LEED®-NC impact database-query application, and the impact assessment process model. In addition, the chapter also discusses the future areas of research.

It is expected that the value of green building construction will be close to $12 billion in 2007 (USGBC 2007). The concept of green buildings has received tremendous interest in the last few years and is gradually becoming part of mainstream construction industry. Additionally, the LEED® green building rating system has been widely accepted by public and private owners, further fueling the demand for green buildings. In context of this interest in green buildings, this research effort focused on the role of constructors in the green building process as integral participants in a project.

Chapter 1 defined the research goal, objectives, scope, and the methodology adopted for this research. Chapter 2 presented a summary of the literature reviewed. The major sections covered include sustainable design and construction, constructor's role in green buildings, and database-query systems and process models. Chapter 3 described the development of the impact matrices with examples of each of the matrices developed. The project phase impact matrix is a preliminary analysis, while the LEED®-NC credit impact matrix is a comprehensive analysis of each LEED®-NC credit's impact on constructors and construction management practices. Chapter 4 described the development of the LEED®-NC impact database-query application. It includes an illustration of how the users will access the database, with examples of major and moderate impact credits. The IAG provided feedback on the LEED®-NC credit impact matrix and the LEED®-NC impact database-query system application.

Chapter 5 is the last phase of the research that describes the development of a process model to identify the impacts of green building programs on constructors. This model was developed based on the methodology steps used for this research. This process model can be helpful in analyzing the impact of green building programs on different construction industry sectors, such as residential, facilities management, renovation contractors, etc.

6.2 Summary of Research Objectives achieved

The following section discusses the steps carried out to achieve the research objectives.

6.2.1 Objective 1

Identify and analyze the impact of LEED®-NC requirements on constructors and construction management practices.

Step 1: Familiarize with LEED® - NC V 2.2 and review existing literature to understand and assimilate the current research in sustainable design and construction.

This step included a detailed review of LEED®-NC V2.2, covered in Chapter 2 and 3. It was achieved through the literature reviewed for categories of sustainable design and construction, construction management, and cost aspects of green buildings and database-query systems and process models.

Step 2: Develop the Project Phase Impact Matrix to map a constructor's role in green buildings during various project phases.

In order to achieve this step, the researcher identified the impacts of green buildings on a constructor's activities during different project phases. The project phase matrix was developed based on the literature reviewed in step II and supplemented with examples from interaction with construction professionals.

Step 3: Conduct case studies through site visits and industry input.

Four case studies were conducted for this research. The data was incorporated in the LEED-NC credit impact matrix, and input from the construction industry professionals working on green building projects was also obtained.

Step 4: Develop the LEED®-NC Credit Impact Matrix to map the impact of LEED®-NC credits on constructor's activities/ practices.

Based on the Project Phase Impact Matrix and data collected from case studies, the LEED®-NC credit impact matrix was developed. This matrix provides a detailed list of impacts of all LEED®-NC credits on significant construction management functions that were identified from the project phase impact matrix. In addition, all LEED®-NC credits were categorized as major, moderate, or some, based on their level of impact on these functions.

Step 5: Based on a constructor's role in different project delivery methods, identify responsibilities in a LEED®-NC *project.*

In this step, for a LEED®-NC project, a constructor's role was identified based on different project delivery methods such as CM at risk, design build, CM as agency, GC lump sum, etc. The responsibilities were obtained from the project phase and LEED®-NC credit impact matrix, based on the constructor's involvement in the project. For instance, in a design build contractual method, the constructor is involved much earlier in the project as compared to a GC lump sum contract, in which the constructor is mostly involved in the project after the design is complete and construction documents have been prepared.

Step 6: Conduct an Industry Advisory Group (IAG) work session, to obtain feedback on the outputs developed in steps 4 and 5.

In this step, the LEED®-NC credit impact matrix was presented to the industry advisory group. The examples and feedback obtained were incorporated.

6.2.2 Objective 2

Develop the database-query system to assist the constructors' in successfully navigating LEED®-NC rating system.

Step – 7: Review literature on database systems to understand their architecture and working mechanism.

This step was conducted as a part of the literature review with one of the categories focusing on database-query systems. This step was instrumental in determining the type of database to be developed, organization of the database, and database entities to be developed for this research, based on the type of information to be stored.

Step – 8: Identify the entities (tables, forms and queries) required for developing the database, create the entity relationship diagram, and develop the rules of data retrieval, based on the LEED®-NC *Credit Impact Matrix.*

This step was accomplished with the help of literature reviewed on database – query systems. Two types of tables were created: impact level and CM function table that acted as the main storage units of information, and queries were developed to sort information from these storage units. Database forms were created for the user interface, in which the information sorted by the query would appear. An entity relationship diagram was developed for the database that established the basic rules of information sorting and retrieval and eliminated any data redundancy. The rules were created to allow future additions in the database. Based on the database components created in the previous step, the LEED-NC impact database was developed in this step.

Step – 9: Develop the database, based on information synthesized in objective 1.

Based on the database components created in the previous step, the LEED®-NC impact database was developed in this step.

Step – 10: Obtain feedback from the IAG.

The database was presented to the IAG to obtain feedback on the user interface and ease of accessing the information. The feedback obtained was incorporated.

6.2.3 Objective 3

Based on the methodology followed in this research, develop a process model for investigating a constructor's role in other green buildings programs such as LEED-Homes, LEED – Commercial Interiors, etc.

Step – 11: Compile the comprehensive methodology steps, followed in objectives 1 and 2.

This was achieved by mapping the process followed in objectives one and two and compiling the steps.

Step – 12: Develop a process model to assess the impact of a green building program on a constructor's activities.

Based on the process mapped above, a process model was developed to identify a constructor's role in a green building program. Detailed tasks required for each phase in the process model were developed in this step.

Step – 13: Illustrate the application of the process model.

This step was accomplished by illustrating the application of the process model, with an example of LEED®- Homes. The illustration identified the impacts of LEED®- H on a homebuilder's processes. A smaller version of the project phase and LEED®- H impact assessments was developed, as a part of the illustration.

6.3 Conclusions and Observations/Inferences

This section presents the conclusions and observations/inferences drawn in this research. This research identifies how constructors can understand the impacts of various

LEED® requirements on their roles and practices in executing green projects, which can equip them to become a value-adding member on a LEED® project team.

One of the primary aspects of understanding the LEED® requirements is to focus on those credits that require constructor's direct involvement. This was achieved by categorization of LEED®-NC credits into major, moderate and some impacts to facilitate the constructors' understanding of their roles in providing input on these credits. This categorization can be of vital importance to the constructors in order for them to plan their activities required to achieve LEED®-NC credits. The major impact credits identified in this research include; SS Prereq - 1 Construction Activity Pollution Prevention and SS Credit 5 Site Development, EA Prereq 1-Fundamental Commissioning of Building Systems and EA Credit 3-Enhanced Commissioning, MR Credit 2-Construction Waste Management and MR Credit 3-7- Materials Reuse, Recycled Content, Regional Materials, Rapidly Renewable Materials, Certified Wood, EQ Credit 3- Indoor Air Quality Management, and EQ Credit 4- Low Emitting Materials. Based on the major impact credits identified in this research, a constructor can contribute in achieving 18 points under the credits mentioned above. This constitutes approximately 26% from a total of 69 points and 2 prerequisites of SS Prereq-1 and EA Prereq-1.

In addition to the impact categories created, constructors' roles in achieving certain major impact credits were similar and discussed collectively. For instance, MR credits 3-7 require that the achieved compliance should be expressed in terms of the cost of the materials, which is furnished by the constructor based on the final cost invoices. Similarly, the efforts required by the constructor in order to comply with SS Prereq 1, also help to achieve the requirements of SS Credit 5, as the intent is similar to SS Prereq-1.

The moderate impact category consists of those credits, which can benefit from a constructor's participation and it includes; SS Credit 3- Brownfield Redevelopment, SS Credit 6- Stormwater Design, WE Credit 2- Innovative Waste water technologies, WE Credit 3- Water Use Reduction, MR Credit 1- Building Reuse, ID Credit 1- Innovation in Design. Although these credits are considerably affected by design decisions, it can be concluded that the constructors' involvement in these credits can help in streamlining their compliance.

The impact of LEED® credits was analyzed on typical CM functions; estimation decisions & project cost, scheduling- activities, durations & logic, project administration and documentation, contracts and agreements, and field operations and subcontractor coordination. Amongst the major impact credits, it was observed that MR credits 3-7, have a significant impact on project cost and estimation decisions. The scheduling-activities, durations & logic CM function were affected by MR credits 3-7 EA prereq-1 and credit 3. In case of MR category, the impact was due to increase in lead-time for procurement and, for commissioning credits, the primary impact was on logic and sequencing of activities. A similar impact on logic and sequencing of activities was also observed due to EQ credit 3 and 4. Increase in project administration and documentation and contractual agreements was evident in most of the major impact credits due to the LEED®-NC documentation requirements, but the impact was dominant for MR credits 3-7. The impact on field operations and subcontractor coordination is mostly apparent in

MR credit 2 – Construction waste management and EQ-credit 3- IAQ management during construction.

6.3.1 Role of Constructor's in LEED®-NC project

Constructors' early and greater participation in green projects is also a function of the project delivery method employed. Green buildings require an integrated team approach, due to their complex requirements. Based on the understanding developed from the literature and interaction with construction professionals it can be summarized that a design build contractual method is the most appropriate project delivery method for green buildings. As observed in interaction with construction professionals and discussed in Chapter 3, however, both CM at risk and CM as agency are the favorable contractual relationships for a green project. In addition, the GC lump sum contract, which is used by a majority of owners, provides fewer opportunities for constructor's involvement during the project's early phases. In such a case, the constructor's experience with LEED® projects and most of the impacts identified in this research can help the construction team to effectively plan for the LEED® requirements and the project's sustainable objectives.

Constructor's early involvement can also help the project team to achieve some of the credits in the Innovation and Design (ID) category. A constructor can make significant contribution in achieving these credits, as most of the exemplary performance credits under ID are construction-based credits, such as MR credit 2 - construction waste management plan, MR credits 3-7, etc. The analysis of all LEED®-NC credits on construction management practices provides a strong case of a constructor's contribution in LEED® projects and the additional responsibilities that constructors may have to assume in a green project. It also reinforces the need for early involvement of constructors in LEED® projects in order to streamline the design and construction processes and utilize the expertise of the constructors and their downstream participants, such as subcontractors.

Early involvement of a constructor can also provide the owner and designer with cost implications of pursing certain LEED®-NC credits. The constructor's team can develop "what-if" scenarios of cost implications of pursuing specific LEED®-NC credits. In addition, the constructor may also undertake life cycle cost analysis of materials and products, while preparing construction documents to determine the optimum solution based on the owner's requirements. A constructor's involvement in the initial phases of a green project can help in educating the subcontractors about the LEED®-NC requirements and their additional responsibilities in a green project, which can help to prepare for these requirements during the project-planning phase. Based on the research work, existing literature, and interaction with construction professionals, some of the significant contributions of constructors in a LEED®-NC project are identified below;

- In case of design build contract, participate in feasibility studies during initial project stages and develop a design based on sustainable design and construction practices.
- Provide conceptual estimates and participate in material selection process.
- Provide input on attempted LEED®-NC credits and work with the design team to devise strategies to achieve them.
- Utilize input of MEP subcontractors to optimize the system design during the energy-modeling phase to optimize the building performance.

- Involve subcontractors in HVAC system design through constructability reviews.
- Educate subcontractors about the project's green goals, such as CWM and IAQ through training sessions and coordinate subcontractors for compliance with LEED requirements during field operations.
- Include additional cost of procurement & storage of materials, commissioning reviews and LEED®-NC documentation in the project estimate.
- Include the impact of green material procurement and commissioning activities on the project schedule; additional activities, increased durations, and/or logic change.
- Compile the LEED®-NC documentation collected from prime contractors, subcontractors, suppliers and manufacturers.
- Include LEED®-NC responsibilities in prime contract and sub contract documents.
- Develop the site logistics plan in compliance with LEED®-NC requirements, including barricading of existing vegetation and other natural habitats.
- Educate the field personnel and subcontractors about the project's green goals, through training sessions.

The concerted conclusions drawn in this research and reiterated above, establish the central role of a constructor in LEED®-NC projects and in the green building movement. In addition, the process model developed by capturing the research methodology, presents a vital tool to recreate these impacts for other green building programs and construction sectors.

6.4 Areas of Future Research

This section discuses some of the future research directions relevant to this research focus. Some research is being conducted on parts of the research focus areas mentioned. The researcher believes, however, that with the current momentum in sustainability and green buildings, there is immense potential in applied research that needs to be explored.

1. **Role of trade contractors in green buildings**

While this research centered on a constructor's role, there is also a need to explore the contribution of trade contractors in green buildings. One of the major concerns of the green building initiative is to reduce the energy consumption of buildings with focus on mechanical and electrical systems. Both the mechanical and electrical contractors can play a pivotal role in the green building process.

2. **Developing a building information model (BIM) for green projects to incorporate the construction management aspects**

Current research in the field of BIM is being pursued that incorporates the design related information of green projects. With the help of the output developed in this research, the construction management information related to green projects can be embedded in the building model, utilized as the project progresses, during different project phases, and based on other green building programs.

3. **Assessing constructor's environmental performance in sustainable projects**

With greater involvement of constructors in green building projects, the need to measure and assess their performance in achieving the sustainable project objectives, such as LEED requirements may also be explored. The consideration of sustainability as an important project objective, in addition to time, cost and quality requires development of parameters to be measured to assess a contractor's performance in a sustainable project.

6.5 Summary

As the demand for LEED®-NC projects continues to grow, it is imperative that the constructor's understand the working of this green building rating system and their role in achieving LEED®-NC credits. This research presents a comprehensive analysis of how LEED®-NC credits influence constructors' activities in implementing these projects. This analysis is a vital tool that can prepare the constructors in successfully navigating LEED® projects. In addition, as the project delivery method affects the extent of constructors' role in executing a project, this research identified these responsibilities under different contractual methods, in context of LEED® projects. These research outputs can facilitate the constructors in effectively contributing to a LEED® project by better understanding their responsibilities.

APPENDICES

APPENDIX A

Example LEED-NC Credit Impact Matrix – MR Credit -2

Construction Waste Management

LEED®- NC CREDIT IMPACTS

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

Divert construction and demolition debris from landfills and incinerators. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.

ESTIMATION DECISIONS & PROJECT COST

1. The constructor needs to assess the recycling facilities near the project site. The cost of implementing a Construction Waste Management (CWM) Plan is a function of various project specific factors such as (Matthiessen & Morris 2004, Mogge 2004, Katz et. al. 2003) :

   - Project location – It is an important factor that affects the cost of implementing a Construction Waste Management Plan. For instance, projects located in downtown areas may have space constraints, which may not allow sorting of waste on site. Consequently, construction waste may be collected as commingled waste on site and waste separation may be done outside the site premises, which may increase the cost of CWM significantly.
   - Site logistics and building layout planning - The project team may decide to rent a space for waste collection and/or sorting outside the project premises due to lack of space on site, increasing the project overhead cost (Winn 2006).

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

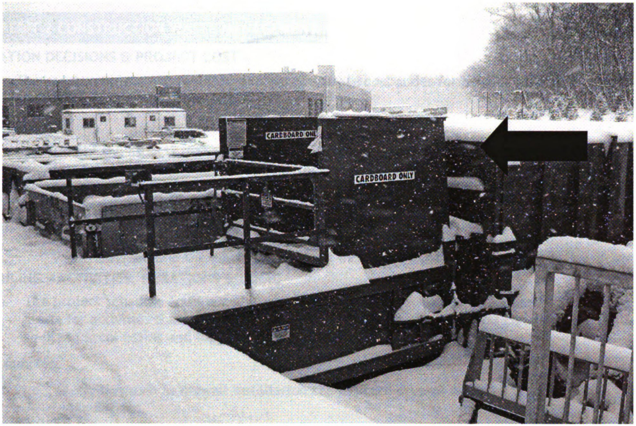
ESTIMATION DECISIONS & PROJECT COST

- Availability of recycling facilities- It may impact the cost of hauling the waste from the project site to the recycling facility. It may also influence the option of on site waste sorting or commingled waste recycling.

Examples:

a. In “Case Study Project - B” about 93% of all construction and demolition waste (6,000 tons) was diverted from landfills. A “gyp monster” was used to grind drywall for use as a soil amendment. The original office building was deconstructed and used as structural fill to help raise the entry roadbed (Case Study Project - B 2007).

b. In “Case Study Project - A,” the project team used a cardboard compactor to offset the cost of collecting and sorting the waste on site (Case Study Project- A 2007). The compactor used is shown in the next slide.



Cardboard Compactor used in “Case Study Project - A” (2007)

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

ESTIMATION DECISIONS & PROJECT COST

2. The constructor may be required to create separate cost codes for assigning the cost associated with waste diversion on the project.

Example:

a. One of the aspects that affected the project control formats, in “Case Study Project- B”, was the creation of a separate cost code for construction waste hauling and recycling. The project team created a separate line item in the project estimate for hauling and recycling the construction waste. After mobilization, the recycling unit provided monthly invoices to the project team for items that were recycled. Cost from these invoices was then transferred to the construction waste cost code. This acted as a record for measuring the quantity of construction waste diverted and the corresponding cost incurred (F1 2007).

SCHEDULING - ACTIVITIES, DURATIONS & LOGIC

1. The project schedule and CWM plan can be tied together such that look-ahead schedules can include alerts for activities that are bound to generate construction waste. This can assist the field personnel to plan for collecting and logging of the waste generated.

Example:

a. Activities such as drywall installation can indicate drywall waste and can help with waste calculations.

b. All demolition activities can be flagged in a schedule as waste generator activities.

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

PROJECT ADMINISTRATION & DOCUMENTATION

1. The constructor may need to identify construction waste haulers and recycling facilities that accept the type of (expected) waste generated on the project site.

Examples:

a. Metal, concrete and asphalt are commonly recycled materials but gypsum wall board requires specialized reprocessing plants (LEED 2005). "Case Study Project - A" was initially not able to recycle drywall due to unavailability of recycling facilities in the project vicinity. Later, a drywall recycling unit in the area was identified and gypsum wall board waste was recycled (Case Study Project- A, 2007).

b. In "Case Study Project- D", the project team decided to recycle metal, electrical cabinets, windows, carpets and ceiling tiles, based on the type of materials recycled by the nearby recycling facilities (Case Study Project- D, 2007).

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

PROJECT ADMINISTRATION & DOCUMENTATION

2. The constructor should prepare a CWM Plan that defines the responsibilities of all subcontractors involved (Klehm 2006). Some of the components of CWM plan include (Seattle/King County 2002 -03, Klehm 2006) :
   - Assign a coordinating personnel, such as a project engineer
   - Identify methods of disposing construction & demolition waste - recycle, reuse, salvage or landfill, based on the options available near the project site.
   - Define waste management goals - 50%, 75% or 95% for Innovation & Design credit
   - Specify on-site handling and storage facilities - provision of different dumpsters or one dumpster for commingled waste.
   - Educate the subcontractors about the goals and objectives of the CWM plan

Examples: Two sample CWM plans are shown in the next slides

a. Construction waste management plan used in "Case Study Project-A" (Case Study Project - A, 2007)

Sample Construction Waste Management Plan (Seattle/ King County 2002-03).

Company: Northwest Best Construction

Project: Northwest Bank Building, Kent, WA **Designated Recycling Coordinator:** John Doe

WASTE MANAGEMENT GOALS:

This project will recycle or salvage for reuse 60% by weight of the waste generated on-site.

COMMUNICATION PLAN:

- Waste prevention and recycling activities will be discussed at the beginning of each safety meeting.
- As each new subcontractor comes on-site, the recycling coordinator will present him/her with a copy of the Waste Management Plan and provide a tour of the recycling areas.
- The subcontractor will be expected to make sure all their crews comply with the Waste Management Plan.
- All recycling containers will be clearly labeled.
- Lists of acceptable/unacceptable materials will be posted throughout the site.

EXPECTED PROJECT WASTE, DISPOSAL, AND HANDLING:

The following charts identify waste materials expected, their disposal method and handling procedures:

MATERIAL	QUANTITY	DISPOSAL METHOD	HANDLING PROCEDURE
Demolition Phase			
Asphalt from parking lot	100 tons	Ground on-site, reused as fill	
Wood Framing	6 tons	Recycled: Wood Recycling Northwest	Separate "clean wood" in clean wood bin
Decorative Wood Beams	300 bd. ft.	Salvaged: Timber Frame Salvaging	Remove by hand, store on-site, load on pallets for pickup
Remaining Materials	8 tons	Landfill: Sound Disposal	Dispose in "trash" dumpster
Construction Phase			
Concrete	2 tons	Recycle: Puget Sound Concrete	Break up any wastes or mistakes and put in concrete bin. Rebar OK
Forming Boards	6 tons	Reuse as many times as possible then recycle: Wood Recycling NW	Stack next to supply of new form boards for reuse. Recycle clean unusable forms in wood recycling bin
Clean Wood Scrap	12 tons	Scraps reused for formwork, fire breaks, etc. Remaining recycled: Wood Recycling NW	Stack reusable pieces next to saw for reuse. Place unusable clean wood in wood recycling dumpster
Scrap Metal	5 tons	Recycle: Seattle Metals	Deposit all metals in metal dumpster
Drywall	10 tons	Subcontractor will recycle & submit reports to recycling coordinator	Either provide container or collect in vehicle for recycling
All other wastes	14 tons	Landfill: Sound Disposal	Dispose of in trash dumpster

Project Title
Project No. XXXXX

XYZ Construction Company

Construction Waste Management Plan
(Case study Project – A, 2007)

Section 1 Introduction

1.1 Purpose

The purpose of the Construction Waste Management Plan (CWMP) is to establish a protocol for implementation of the Construction Waste Management Initiative (CWMI), specifically the handling and disposal of demolition and construction debris. The CWMI is a component of the LEED program and is intended to minimize the negative environmental and cost impacts of construction waste and debris.

1.2 Scope

This plan defines the requirements of the Construction Waste Management Initiative established by XYZ Construction Company in accordance with Credit MR 2.1of the LEED-NC 2.2 module. For LEED Projects registered under another LEED-NC version or another LEED product, transferability of this CWMP should be confirmed – relative modifications will be understood if not reflected in this CWMP. The CWMP will be implemented during the "Demolition Phase" and "Construction Phase" of the project. XYZ Construction Company and its subcontractors will execute both phases of the CWMP.

1.3 Definitions

1.4 Quality Assurance

1.5 Documentation

1.6 Training

Project Title
Project No. XXXXX

XYZ Construction Company

Construction Waste Management Plan (Cont.)
(Case study Project – A, 2007)

Section 2		**Implementation**
	2.1	Documents
	2.2	Reporting
	2.3	Execution
Section 3		**Certification**
	3.1	Requirements
	3.2	Turnover

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

PROJECT ADMINISTRATION & DOCUMENTATION

3. The constructor should maintain an active record of total construction waste generated and % diverted, recycled, reused and salvaged. Shown in the next slide is an example of records indicating the waste diverted in the "Case Study Project - A".

Container Ticket Number and Haul Date	Total Tonnage (sum of concrete, metal, wood & other residual	Concrete Tonnage (diverted)	Metal Tonnage (diverted)	Wood Tonnage (diverted)	Paper & Cardboard products Tonnage (diverted)	Other diverted Tonnage (explain in comments)	Total diverted Tonnage	Residual or Trash Tonnage (land filled)	% Recycled /diverted Material	Name and location material was sent to	Comments. If land filled explain why material was not diverted. If other recycled material, include description of material
2005 Totals	759.34	393.50	23.30	72.60	3.20	12.94	505.34	254.00	66.55%		Drywall was also diverted
January 2006 Totals	166.40	40.95	16.66	6.00	0.00	18.93	82.54	83.86	49.60%		Drywall was also diverted
February 2006 Totals	162.47	40.00	19.47	30.00	4.35	41.62	135.44	27.03	83.36%		Drywall was also diverted
March 2006 Totals	171.48	68.69	18.23	24.00	3.95	11.20	126.07	45.41	73.52%		Drywall was also diverted
April 2006 Totals	162.07	34.91	10.48	0.00	0.78	85.37	131.54	30.53	81.16%		
May 2006 Totals	205.42	55.00	11.98	24.00	3.05	59.01	153.04	52.38	74.50%		
June 2006 Totals	122.66	0.00	10.08	23.00	3.22	55.28	91.58	31.08	74.66%		
July 2006 Totals	130.66	0.00	9.44	4.00	2.63	81.85	97.92	32.74	74.94%		
August 2006 Totals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
September 2006 Totals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
October 2006 Totals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
November 2006 Totals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
December 2006 Totals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		

Project Summary	2005 Totals	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	YTD Total	2005 2006 Total
Concrete	393.30	40.95	40.00	68.69	34.91	55.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	239.55	633.05
Metal	23.30	16.66	19.47	18.23	10.48	11.98	10.08	9.44	0.00	0.00	0.00	0.00	0.00	96.34	119.64
Wood	72.40	6.00	30.00	24.00	0.00	24.00	23.00	4.00	0.00	0.00	0.00	0.00	0.00	111.00	183.40
Paper/Cardboard	3.20	0.00	4.35	3.95	0.00	3.03	3.22	2.63	0.00	0.00	0.00	0.00	0.00	17.98	21.16
Other diverted	12.94	18.93	41.62	11.20	85.37	59.01	55.28	81.85	0.00	0.00	0.00	0.00	0.00	353.26	366.20
Subtotal diverted	505.34	82.54	135.44	126.07	131.54	153.04	91.58	97.92	0.00	0.00	0.00	0.00	0.00	818.13	1323.47
Residual/Trash	254.00	83.86	27.03	45.41	30.53	52.38	31.08	32.74	0.00	0.00	0.00	0.00	0.00	303.03	557.03
Subtotal	759.34	166.40	162.47	171.48	162.07	205.42	122.66	130.66	0.00	0.00	0.00	0.00	0.00	1121.16	1880.05
% of Recycled material	66.55%	49.60%	83.86%	73.52%	81.16%	74.50%	74.66%	74.94%	0.00%	0.00%	0.00%	0.00%	0.00%	72.97%	70.38%

The Field personnel record the monthly diversion quantities and update this sheet for final LEED submittal.

Construction waste calculation summary sheet (Case Study Project - A, 2007)

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

PROJECT ADMINISTRATION & DOCUMENTATION

4. The constructor may be required to develop a separate set of LEED certification submittals and control formats during the project planning phase.

Example:

a. In the "Case Study Project- A," the field personnel prepared the basic spreadsheet for waste collection, which was given to the waste collection and the hauling agency. The waste haulers calculated the amount of waste generated, populated the waste collection spreadsheet, and returned it to the project team (Case Study Project- A 2007).

5. **Documentation requirements (LEED 2005):**

Documentation requirements for this credit may include,

- Construction waste calculation in the LEED letter template, type of waste, recycler/landfill, quantity of waste diverted along with way slips and hauler receipts.
- Documentation of recovery rate in case of commingled waste.
- Assumptions for synergies achieved from other credits such as, MR -1 Building Reuse
- Narrative that outlines the projects waste management approach, and includes the CWM plan.

Example: According to GVRD (2004),"...typically the plumber will diligently collect all scraps of copper piping and recycle it. LEED only asks that the plumber provide the contractor and the LEED Coordinator with a way slip from the Recycling Depot for each load as proof".

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

PROJECT ADMINISTRATION & DOCUMENTATION

6. Achieving this LEED credit for reducing waste at source by the constructor will require a quantification of the amount of waste diverted (waste that was not generated, in the first place). In case the project teams can systematically show the calculations, achieving MR credit - 2, is feasible (Winn 2006).

7. Achieving the 95% level of construction/demolition waste diversion for an ID credit is generally difficult, unless there are existing materials available on site or part of a building is being renovated. When this is the case, additional coordination for recording construction waste generating activities may be needed to attain this credit (C2 2007) .

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

CONTRACTS & AGREEMENTS

1. The constructor may include the requirements of CWM in the subcontractor's work scope.

Examples:

a. CWM - related work scope language used on "Case Study Project-A" (2007).

> **"It is the responsibility of the subcontractor to comply with site specific Construction Waste Management Program. This program requires all construction waste to be sorted by material type and disposed of in separate dumpsters. The contractor will provide five dumpsters onsite for each of the following materials: wood, concrete, metal, cardboard and trash. The items collected from the wood, concrete, metal and cardboard dumpsters will be recycled.**
>
> **Subcontractors who fail to comply with the construction waste management program will be held responsible for clean up. In addition, fines may be imposed for non compliance. Your commitment an cooperation are essential to having a good LEED program."**

b. On a LEED restoration project, in Washington D.C., separate contracts were signed between the constructor and the waste haulers for different types of waste generated on-site (Gardi 2007).

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

CONTRACTS & AGREEMENTS

2. The constructor may include the requirements of CWM (from the general requirements of project specifications) in the responsibilities of subcontractors.

Example: Illustrated below is part of Division - 1: General Requirements, with a specific section for construction waste management.

Table of Contents - Volume I

DIVISION 1 - GENERAL REQUIREMENTS

01094	DEFINITIONS
01100	INDOOR AIR QUALITY DURING CONSTRUCTION
01101	ENVIRONMENTAL REGULATIONS
01340	SUBMITTALS
01410	TESTS AND INSPECTIONS
01412	CODES, REGULATIONS, AND GUIDELINES
01500	CONSTRUCTION FACILITIES, TEMPORARY CONTROLS AND UTILITIES
01505	CONSTRUCTION WASTE MANAGEMENT
01565	INTERIM INFECTION CONTROL MEASURES (IICM) (SBS)
01610	DELIVERY, HANDLING AND STORAGE OF MATERIAL AND EQUIPMENT
01640	PRODUCT OPTIONS AND SUBSTITUTIONS AFTER EXECUTION OF CONTRACT
01670	SYSTEM DEMONSTRATIONS
01701	CONTRACT CLOSEOUT
01710	CLEANING
01720	PROJECT RECORD DOCUMENTS
01730	OPERATION AND MAINTENANCE DATA
01740	WARRANTIES AND GUARANTIES
01750	SPARE PARTS AND MAINTENANCE MATERIALS
01800	COMMISSIONING REQUIREMENTS
01970	ABBREVIATION - TERMINOLOGY

Inclusion of LEED requirements as part of subcontractor responsibilities in Division -1, General requirements, facilitates compliance. Shown here is part of the project specifications, under which a separate section is devoted to construction waste management. Also, seen here are other sections pertinent to other LEED credits discussed in the next sections.

CWM section: Division - 1, General requirements (Case Study Project- - A 2007)

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

CONTRACTS & AGREEMENTS

3. The constructor may require the subcontractors to submit the construction waste log, as part of the general requirements (Case Study Project - D, 2007).

Examples:

a. In "Case Study Project- D", the constructor included a specific section for construction waste management in Division - 1, General Requirements for monthly waste collection report, as shown in the next slide.

b. In "Case Study Project- D", the constructor also required the subcontractors to calculate the savings incurred by implementing the construction waste management plan. As part of the general requirements, the subcontractors were expected to submit a cost analysis of savings resulting from diverting the waste from the landfill. The calculation required is shown in the subsequent slides.

FIELD OPERATIONS & SUBCONTRACTOR MANAGEMENT

1. Field personnel should allocate space on the site for waste collection and sorting while preparing the site utilization plan.
2. The constructor is responsible for educating the subcontractors and craft workers about CWM efforts (Klehm 2006).

Example: Initial training sessions and tool box meetings can be a useful source for educating the subcontractors. The constructor should also include signs in various languages near waste dumpsters to facilitate the work crews in collecting and sorting different types of wastes on-site (Klehm 2006).

SUBMITTALS

B. Waste reduction progress reports: concurrent with each application for payment, submit 3 copies of report. Include separate reports for removals and construction waste. Include the following information:

1. Material category
2. Generation point of waste
3. Total quantity of waste in tons
4. Quantity of waste salvaged, both estimated and actual in tons.
5. Quantity of waste recycled, both estimated and actual in tons.
6. Total quantity of waste recovered (salvaged plus recycled) in tons.
7. Total quantity of waste recovered (salvaged plus recycled) as a percentage total waste.

Sample Submittal Requirements for Construction Waste Progress Reports (Case Study Project- D, 2007)

D. Cost/ revenue analysis: Indicate the total cost of waste disposal as if there was no waste management plan and net additional cost or net savings resulting from implementing waste management plan. Include the following:

1. Total quantity of waste
2. Estimated cost of waste disposal (cost per unit). Include hauling and tipping fees and cost of collection containers of each type of waste.
3. Total cost of disposal (with no waste management).
4. Revenue form salvaged materials.
5. Revenue form recycled materials.
6. Savings in hauling and tipping fees by donating materials.
7. Savings in hauling and tipping fees are avoided.
8. Handling and transportation costs. Include cost of collection containers for each type of waste.
9. Net additional cost or net savings from waste management plan.

Sample Submittal Requirements for Construction Waste Progress Reports (Case Study Project - D, 2007)

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

FIELD OPERATIONS & SUBCONTRACTOR MANAGEMENT

3. The field personnel need to coordinate that construction waste to be recycled/ reused or salvaged is not contaminated by other hazardous waste, food items etc. (LEED 2005). Planning of CWM operations at the site level becomes a part of construction operations (A4 2006). The success of the project specific CWM plan is directly related to the ability of the superintendent to explain and enforce it (C2 2007).

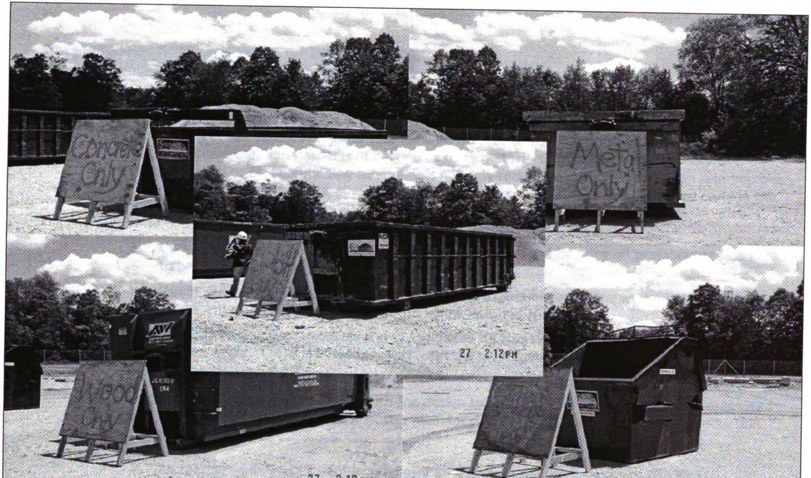
Example: In Case Study Project - A, the field team posted signs of different waste types to assist the workers in complying with the CWM plan, as shown in the next slide (Case Study Project- A 2007).

4. Field personnel responsible for subcontractor coordination should either keep track of the weight of existing concrete, masonry and asphalt which may be used as fill, from the amount of construction waste being diverted or require the subcontractors to give record of such materials (LEED 2005).

5. Waste collection and sorting may have to be done outside the project site. This may add cost and also require adequate planning by the field personnel (Winn 2006).

6. The constructor should consider posting a sign indicating that the project is a LEED project, and that all involved (subcontractors, suppliers, workers etc.) need to follow the CWM plan (C2 2007).

CWM efforts during field operations (Case Study Project - A 2007)



CWM efforts during field operations (Case Study Project - A, 2007)

MR CREDIT 2 CONSTRUCTION WASTE MANAGEMENT

OTHER CONSTRUCTOR - RELATED

1. One of the main tenets of CWM is to reduce the amount of waste generated at source (Pulaski et al. 2004, Riley et. al. 2003). A broader role for a constructor is to make the owner and the designer aware of constructability aspects of certain building materials, products, and components. Prefabrication of certain building components not only reduces waste on-site but can also improve construction quality. If inputs, similar to these from the constructor, can be included early in the project, it can benefit the overall LEED project objectives.

   Examples:

   a. On a LEED project, waste reduction at source was achieved by using all prefabricated and ready to be installed wiring (A1 2006).

   b. Use of preassembled building products that help to reduce packaging waste and save cost such as, pre-manufactured outlet boxes with whips installed (Gardi 2006).

2. Packaging of construction materials and products constitutes one of the biggest sources of construction waste. There is a need to work with the manufacturers and suppliers to reduce or optimize packaging (D1 2006).

3. Reducing the waste in collaboration with the design team is feasible with use of certain optimized sizes of materials that generate less waste. Modular design helps to achieve the waste reduction at source.

   Example:

   a. Increasing wall height to 10’ instead of 9’6” may help to eliminate waste (D1 2006).

4. INNOVATION & DESIGN PROCESS: Divert 95% or greater of the total waste generated

   i. **In order to achieve a 95% or greater waste diversion, both the designer and constructor will have to work together to achieve the target.**

   Example:

   a. **The constructor can highlight those materials which are likely to generate more waste and that do not have any recycling facility nearby. In such circumstances the constructor should communicate with the designer, the need for standardizing the size of such materials in the design. The constructor can also suggest the designer to either change material specification or reduce its quantity so that it remains within the 5% waste target.**

   b. **To achieve this ID credit, it is important to include the required percentage (95%) of waste to be diverted in the subcontract documents. This is necessary as the respective subcontractors should be aware of their responsibility in achieving diversion of increased waste percentage.**

5. **The 95% diversion requirement should be encouraged in the construction documents.**

Example: In "Case Study Project - C", the expected waste from the construction operations was first identified and the probable quantity to be diverted, was calculated in advance. This analysis helped the project team in achieving a realistic target of construction waste diverted (F1, 2007).

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