A Six Sigma-Based Approach to Leadership in Energy and Environmental Design for Existing Buildings: Operations and Maintenance

by

Kimberly Eve Furphy

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved November 2010 by the
Graduate Supervisory Committee:

Nicholas Hild, Chair
Larry Olson
Kenneth Sullivan

ARIZONA STATE UNIVERSITY

December 2010

ABSTRACT

With increasing interest in sustainability and green building, organizations are implementing programs such as Leadership in Energy and Environmental Design for Existing Buildings: Operations and Maintenance (LEED-EB) in order to focus corporate sustainability goals on the operations of a facility and the practices of the building occupants. Green building programs help reduce the impact of a facility and bring about several environmental benefits including but not limited to energy conservation, water conservation and material conservation. In addition to various environmental benefits, green building programs can help companies become more efficient. The problem is that organizations are not always successful in their pursuits to achieve sustainability goals. It frequently take years to implement a program, and in many cases the goals for sustainability never come to fruition, when in the mean time resources are wasted, money is spent needlessly and opportunities are lost forever. This thesis addresses how the Six Sigma methodologies used by so many to implement change in their organizations could be applied to the LEED-EB program to help companies achieve sustainability results. A qualitative analysis of the Six Sigma methodologies was performed to determine if and how a LEED-EB program might utilize such methods. The two programs were found to be compatible and several areas for improvements to implementing a LEED-EB program were identified.

DEDICATION

I would like to dedicate this thesis to my family. This endeavor has required many long weekends of studying, where my common phrase has been, “I am almost done…no really I am almost done.” Thank you for putting up with me and for keeping the house running while I’ve been finishing my degree. I love you. Now we can go have some fun.

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CHAPTER 1 INTRODUCTION

Introduction to LEED

The green building industry has grown significantly over the past decade. At the forefront of this movement is the United States Green Building Council (USGBC). The USGBC was founded in 1993 and for the next five years the USGBC task force worked to develop a standard for the building industry that could be used to improve sustainable development (Kibert, 2005, p. 3). The USGCB, with the assistance of multiple specialists, developed a program to assist architects, engineers, developers, and construction professionals in designing, building and operating buildings that are better for the environment, better for building occupants and show significant operational cost savings for building owners. This program is called Leadership in Energy and Environmental Design (LEED).

Building Design+Construction (2006) report how the industry has increased interest in green building. They state, “What started out as a charismatic environmental crusade has matured into an established sector of the U.S. construction industry” (p. 1). The financial sector is taking a look at green building and the potential promise of green buildings commanding premium rents (Building Design+Construction, 2006, p.1). Additionally, with energy costs increasing and reduced water supply in many regions of the United States and throughout the world, building developers and organizations are interested in learning about ways to reduce their impact, especially when that reduction can also mean an increase in profits or costs saved.

With this increasing interest in sustainability and green building, organizations are implementing programs such as LEED for Existing Buildings: Operations and Maintenance in order to focus corporate sustainability goals.

Statement of the Problem

The failed LEED-EB project.

This thesis provides an analysis of how Six Sigma could be used to improve the evaluation, design and implementation phases of a LEED-EB project. The research question arose as a result of a Phoenix based company that was unsuccessful in moving past the initial phases of LEED analysis. A LEED-EB project was to be performed at a 63,000 square foot, two story, single tenant office building located in Phoenix, AZ. Each LEED-EB credit was analyzed and a cost of implementation was associated to each credit. The owner selected which options they would be most interested in implementing and a team of professionals conducted the analysis of each LEED credit to determine which would be the most cost effective.

The analysis of the above references LEED-EB project provided data that supported the implementation of sustainability goals. The result would be a LEED Certified facility, significant cost savings, and environmental benefits. The results of the analysis indicated that the project would have paid for itself within five years for a Certified Level facility. Additionally, there would have been future environmental and economic benefits for many years to come, so it reasons that the problem did not arise in the lack of LEED-EB benefits, but in the methodology used to direct and steer organizational change and gain the final approval from top managers and CEOs. The President of the company was very interested in moving forward in the beginning, but the project stagnated, lost momentum and was eventually postponed indefinitely.

Professional significance of the problem.

Organizations are not always successful in their pursuits to achieve LEED-EB certification. It frequently takes years to implement a LEED-EB program and in some cases it never becomes implemented, when in the meantime precious resources and opportunities are lost forever. In fact, Building Design+Construction (2006) reported that only 20% of construction industry professionals when surveyed had reported achieving a green certification for at least one project (p. 6). Additionally, 39% of construction industry professionals reported that they had started projects to include sustainable design principles, but eventually withdrew due to costs or uncertainty (Building Design+Construction, 2006, p.8).

As of October 3, 2010, the USGBC reports that 3,530 facilities have registered to start the LEED-EB certification process, however only 739 have actually been certified (USGBC, 2010). This constitutes a success rate of only 21%.

It is important to note that the reason many organizations state that they decide not to pursue green building is the perception that it has a high first cost. In actuality, the first cost of implementing sustainable design elements is decreasing as more and more of the product manufacturers produce sustainable materials and other sustainable products are becoming more and more mainstream. Additionally, companies want to know how much LEED-EB is going to cost them, but there is no one size fits all answer to that question. It is better to determine what greening the company is going to cost for a specific project (David Langdon, 2007, p. 55).

If the companies had a set process or methodology for determining costs and assessing the value to the organization before they started a LEED-EB project, perhaps the implementation and completion rate of LEED-EB would increase. The first step to answering this question is to find a methodology that has demonstrated success in industry that could be combined with the LEED-EB program. Utilizing Six Sigma methodologies on LEED-EB projects may provide techniques that could increase the success rate of implementing sustainability goals.

In searching for a better method for successfully implementing change in a corporation, research and literature on the benefits of Six Sigma in creating an environment of organizational improvements became apparent. It came to mind that Six Sigma might be a tool or a methodology that could be utilized to make improvements to the various steps of a

LEED-EB project. If the failed LEED-EB projects had used a better methodology for implementation, perhaps they would have been successful in accomplishing all of the valuable goals that were originally identified. Some reasons that the project might have failed to deploy may be associated with poor communication on project progress, lack of commitment from leadership, lack of time dedicated by in-house employees to make the project successful, and lack of tools to communicate effectively about the results of the evaluation. Six Sigma may provide the answer to overcome these barriers.

According to studies by Roth and Northwest (2006), Snee (2010), Calia et al. (2007) and others, companies have been successful in implementing organizational change through the use of Six Sigma methods. If Six Sigma methods can be used to assist LEED-EB projects and produce results in a timely manner, it could potentially save the company resources and provide other benefits.

Scope of Work

Six Sigma can be used as a methodology to assist companies in making great improvements to processes within their organization (Roth and Northwest, 2006, Snee, 2010, and Calia et al., 2007). To determine Six Sigma principles can be combined with LEED-EB project requirements, Six Sigma tools and methods have been analyzed in an effort to align them with existing LEED-EB processes to develop a Six Sigma LEED-EB project road map.

Objectives

- This thesis discusses the history and details of both the LEED-EB and Six Sigma programs.
- A literature review of projects that have utilized Six Sigma including industries outside of manufacturing was performed. This thesis discusses the success and failure of these programs.
- An analysis of the compatibility of the Six Sigma methodologies and the LEED-EB programs was performed, including discussion of which Six Sigma tools and methodologies may be utilized as a technique by a LEED-EB project.

Limitations

This thesis is a qualitative analysis of Six Sigma methodologies and their potential impact on a LEED-EB project. The thesis does not cover research on the actual impact of implementing a Six Sigma-based approach.

Assumptions

The thesis assumes that Six Sigma methodologies have not been used by others to support a LEED-EB project.

CHAPTER 2 LITERATURE REVIEW

In order to understand how the two programs can be merged, it is imperative to understand how each of them works independently. This section discusses both LEED and Six Sigma, where they are used, what tools are used, the benefits of the programs, and the history.

An Overview of LEED

LEED is a program that can be used as a guide for green building design, construction and operation. The purpose of green building is to reduce the environmental impact of the buildings we live in and work in each day. Green building is equivalent to sustainable construction or sustainable operations. The seven principles of sustainable construction as described by Kibert (2005, p. 9) are:

1. Reduce resource consumption (reduce)
2. Reuse resources (reuse)
3. Use Recyclable resources (recycle)
4. Protect Nature (nature)
5. Eliminate toxics (toxics)
6. Apply life-cycle costing (economics)
7. Focus on quality (quality)

Land resources, energy and atmosphere, water and ecosystems are all impacted by the built environment. “Buildings consume approximately 39% of the energy and 74% of the electricity produced annually in the

United States, according to the U.S. Department of Energy" (USGBC, 2009, p. 123). Additionally 5 five billion gallons of potable water are used to flush toilets each day and approximately 1.6 pounds of solid waste are produced per employee at work each day (USGBC, 2009, p. xi).

The benefits of using LEED as a guide to design, construct and operate buildings include financial savings, improved building occupant health and productivity and environmental benefits such as pollution prevention. Students in day-lit schools have been shown to benefit from increased natural lighting (a common design in LEED buildings) with improved test scores. Improved building design has been attributed to a productivity gain of 16%, less absenteeism, and higher work quality. Projects have diverted construction waste from landfills through recycling and reuse efforts. Energy efficiency measures bring significant financial returns for building owners and leases. For instance, the Joe Serna Jr. Environmental Protection Agency Headquarters Building (Cal/EPA) in Sacramento, California saves $610,000 each year, due to energy efficiency measures installed (USGBD, 2009, p. xi).

There are several programs to choose from within LEED. They include LEED for Existing Buildings: Operations and Maintenance (LEED-EB or LEED-EB: O&M), LEED for New Construction (LEED-NC), LEED for Schools, LEED for Core and Shell, LEED for Commercial Interiors (LEED-CI), LEED for Neighborhood Development (LEED-ND) and LEED for Homes. Each of these programs, with the exception of

LEED-EB, each of these programs are focused on the original design and construction of a facility. LEED-EB on the other hand is focused on the operations of a facility. See Figure 1 for an illustration of each of these LEED programs (*http://www.usgbc.org/DisplayPage.aspx?CMSPageID=222)*.

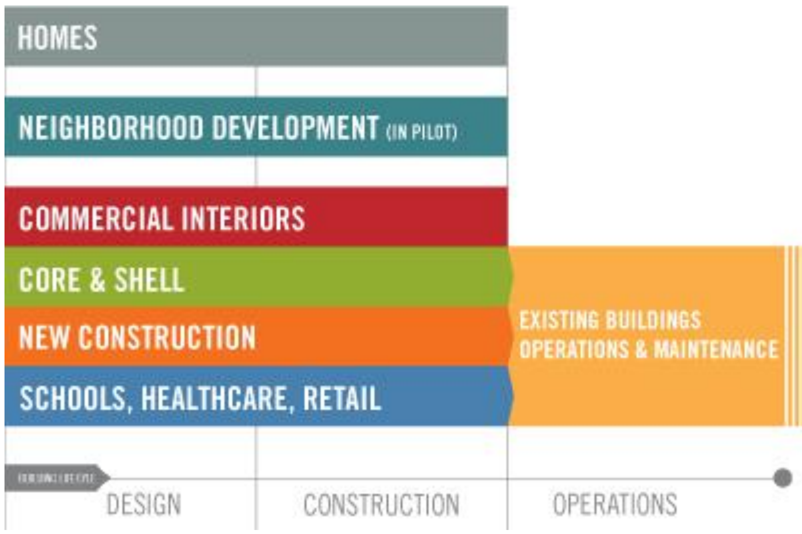

Figure 1. USGBC LEED Programs as of 2010 (USGBC, 2010).

Each of the LEED programs are points based, meaning if you earn a certain number of points, your facility achieves LEED certification and earns a specific level of LEED, depending on the number of points earned. The levels of LEED certification that may be achieved include (from lowest to highest): Certified, Silver, Gold and Platinum.

This paper focuses on LEED-EB. The point distribution for LEED-EB can be seen in Figure 2.

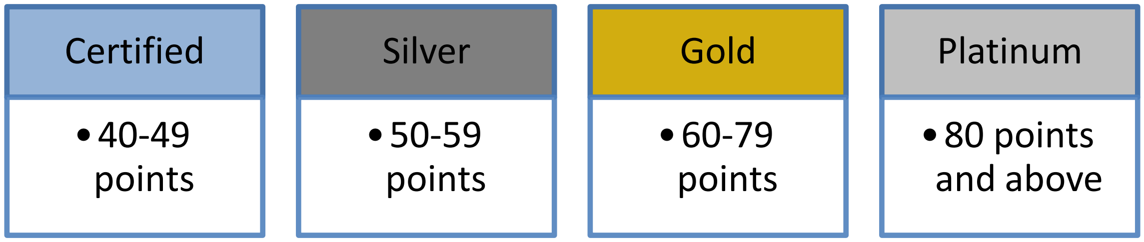

Figure 2. Point distribution and certification levels of the LEED-EB program (USGBC, 2009).

Information on how to achieve these points can be found in the USGBC *LEED Reference Guide for Green Building Operations and Maintenance* (2009). This guide enables professionals to follow a path towards sustainability through water savings, energy efficiency, waste reduction, improved indoor air quality and green purchasing. Several versions of the reference guide exist as the program is continuously undergoing evaluation and improvements are made. The following categories were developed to assist professionals in achieving points towards certification:

- Sustainable Sites (SS)
- Water Efficiency (WE)
- Energy and Atmosphere (EA)
- Materials and Resources (MR)
- Indoor Environmental Quality (IEQ)
- Innovation in Operations (IO)
- Regional Priority (RP)

Each category focuses on specific aspects of green building. According to the USGBC (2009), "The Sustainable Sites (SS) credit section addresses the environmental concerns related to building landscape, hardscape, and exterior building management practices" (p. 1). Specifically, SS focuses on implementing effective grounds maintenance, practicing low-impact hardscape strategies, planting sustainable landscapes, reducing emissions associated with transportation, protecting surrounding habitat, managing storm water run-off, reducing the heat island effect and eliminating light pollution. Some examples of SS projects might include implementing corporate incentives to support an employee carpooling program or planting native vegetation, covering 25% or more of the landscape with ecologically appropriate features including vegetation, water bodies, rock, etc. (USGBC, 2009, p. 23 and 35).

The Water Efficiency (WE) credits support efficient use of precious water resources, by encouraging "the use of strategies and technologies that reduce the amount of potable water consumed in buildings" (USGBC, 2009, p. 77). The goals of the WE credits are to monitor water consumption performance, reduce indoor potable water consumption, reduce water consumption to save energy and improve environmental well-being, and practice water-efficient landscaping (USGBC, 2009, p. 78). With over 43.3 billion gallons of water consumed each day in the United States (an increase of 12% from 1990 to 2000) as estimated by the U.S. Geologic Survey, reductions in water consumption through greater efficiency can be met by implementing a successful LEED-EB: O&M program (USGS, 2009, p. 77).

The Energy and Atmosphere (EA) credits promote three activities: monitoring and improving building energy performance, eliminating chlorofluorocarbons (CFCs) and using renewable energy. Through the implementation of the EA credits, building construction is modified, equipment is retrofitted, and commissioning of systems is performed to enable energy efficiency. The release of CFC's are reduced to prevent the destruction of ozone molecules in the stratosphere, thereby reducing the earth's ability to screen out harmful UV radiation. Additionally, alternative, renewable energy sources are implemented thereby reducing demand on sources of energy that have high levels of pollution (USBGC, 2009, p. 124).

Materials and Resources (MR) credits can "reduce the quantity of waste while improving the building environment through responsible procurement practices" (USGBC, 2009, p. 235). The following measures are promoted through the implementation MR credits: selecting sustainable materials, practicing waste reduction strategies, reducing waste at its source, reusing and recycling and reducing mercury pollution (USGBC, 2009, pp. 235-236).

Indoor Environmental Quality (IEQ) credits benefit the building occupants. According the USGBC (2009) "Americans spend an average of 90% of their time indoors, and the quality of the indoor environmental therefore has a significant influence on their well-being, productivity, and quality of life" (p. 325). In fact, by improving the indoor environmental quality of a facility, building owners can reduce and eliminate health and liability concerns associated with building-related illnesses and sick building syndrome. Additionally, potential savings and productivity gains can be attributed to improvements to indoor environmental quality. When the indoor environment is healthier, building occupants take fewer sick days and productivity increases. It is estimated that by improving indoor environmental quality in the United States, savings could be as much as $6 billion to $14 billion dollars savings on respiratory illnesses each year, $1 billion to $4 billion from reduced allergies and asthma, $10 billion to $30 billion from reduced sick building syndrome symptoms, and $20 billion to $160 billion from direct improvements to employee performance which is not related to improved health (USGBC, 2009, p. 325). Thus the IEQ credits can bring significant savings and many health benefits to companies and their employees. The performance measures recommended by the IEQ credits include improving ventilation, managing air contaminants, implementing green cleaning, specifying less harmful chemicals, allowing occupants to control desired settings, and providing day-lighting and views (USGBC, 2009, pp. 325-327).

The credits that can be achieved through the Innovations in Operations (IO) section involve implementing new technologies and methods that are not available through other options in the program. If a company develops a new strategy for improving the sustainability of the operations, but the credit is not available elsewhere in the program, the company can request to earn points through this innovation option. If the company working to certify a facility utilizes the expertise of a LEED Accredited Professional (AP), they can earn one additional credit. A LEED-AP is a professional who has demonstrated expertise in the area of sustainability and has passed a rigorous examination to earn the status of LEED-AP. A LEED-AP can be a hired consultant or an in-house representative, either way a credit can be earned for having a LEED-AP on the team. Finally, a point can be earned under IO for agreeing to document the costs associated with building operations.

The Regional Priority (RP) credit is a new addition as of 2009, and was added to more appropriately weight the credits that are particularly important to different regions. For instance, in Phoenix, AZ water efficiency is extremely important; therefore additional points can be earned if the project earns a particular level of water efficiency. A list of all regions and the associated priority points is available on the USGBC website at www.usgbc.org (USGBC, 2009, p. 285).

Each of these categories (SS, WE, EA, MR, IEQ, IO, and RP) is further broken down into prerequisites and credits. Prerequisites include things that must be performed in order to achieve any level of certification. On the other hand, credits are optional; however a minimum of 40 points must be achieved in order to earn the first level of certification. The more credits achieved, the more points are awarded the project. Tables 1 through 7 provide a breakdown of every category, credit, credit description and possible points for the LEED-EB: O&M program (USGBC, 2009).

Table 1

Sustainable Sites Credits (USGBC, 2009)

Sustainable Sites Credit	Credit Description	Available Points
SS Credit 1	LEED Certified Design and Construction	4
SS Credit 2	Building Exterior and Hardscape Management Plan	1
SS Credit 3	Integrated Pest Management, Erosion Control, and Landscape Management Plan	1
SS Credit 4	Alternative Commuting Transportation	3-15
SS Credit 5	Site development - Protect or Restore Open Habitat	1
SS Credit 6	Stormwater Quantity Control	1
SS Credit 7.1	Heat Island Reduction - Nonroof	1
SS Credit 7.2	Heat Island Reduction - Roof	1
SS Credit 8	Light Pollution Reduction	1
TOTAL		**26**

Table 2

Water Efficiency Credits (USGBC, 2009)

Water Efficiency Credit	Credit Description	Available Points
WE Prerequisite 1	Minimum Indoor Plumbing Fixture and Fitting Efficiency	Required
WE Credit 1	Water Performance Measurement	1-2
WE Credit 2	Additional Indoor Plumbing Fixture and Fitting Efficiency	1-5
WE Credit 3	Water Efficient Landscaping	1-5
WE Credit 4	Cooling Tower Water Management	1-2
TOTAL		**14**

Table 3

Energy and Atmosphere Credits (USGBC, 2009)

Energy and Atmosphere Credit	Credit Description	Available Points
EA Prerequisite 1	Energy Efficiency Best Management Practices – Planning, Documentation, and Opportunity Assessment	Required
EA Prerequisite 2	Minimum Energy Efficiency Performance	Required
EA Prerequisite 3	Fundamental Refrigerant Management	Required
EA Credit 1	Optimize Energy Efficiency Performance	1-18
EA Credit 2.1	Existing Building Commissioning – Investigation and Analysis	2
EA Credit 2.2	Existing Building Commissioning – Implementation	2
EA Credit 2.3	Existing Building Commissioning – Ongoing Commissioning	2
EA Credit 3.1	Performance Measurement – Building Automation System	1
EA Credit 3.2	Performance Measurement – System-Level Metering	1-2
EA Credit 4	On-site and Off-site Renewable Energy	1-6
EA Credit 5	Enhanced Refrigerant Management	1
EA Credit 6	Emissions Reduction Reporting	1
TOTAL		**35**

Table 4

Materials and Resources Credits (USGBC, 2009)

Materials and Resources Credit	Credit Description	Available Points
MR Prerequisite 1	Sustainable Purchasing Policy	Required
MR Prerequisite 2	Solid Waste Management Policy	Required
MR Credit 1	Sustainable Purchasing – Ongoing Consumables	1
MR Credit 2	Sustainable Purchasing – Durable Goods	1-2
MR Credit 3	Sustainable Purchasing – Facility Alterations and Additions	1
MR Credit 4	Sustainable Purchasing – Reduced Mercury in Lamps	1
MR Credit 5	Sustainable Purchasing – Food	1
MR Credit 6	Solid Waste Management – Waste Stream Audit	1
MR Credit 7	Solid Waste Management – Ongoing Consumables	1
MR Credit 8	Solid Waste Management – Durable Goods	1
MR Credit 9	Solid Waste Management – Facility Alterations and Additions	1
TOTAL		**10**

Table 5

Indoor Environmental Quality Credits (USGBC, 2009)

Indoor Environmental Quality Credit	Credit Description	Available Points
IEQ Prerequisite 1	Minimum Indoor Air Quality Performance	Required
IEQ Prerequisite 2	Environmental Tobacco Smoke (ETS) Control	Required
IEQ Prerequisite 3	Green Cleaning Policy	Required
IEQ Credit 1.1	Indoor Air Quality Best Management Practices – Indoor Air Quality Management	1
IEQ Credit 1.2	Indoor Air Quality Best Management Practices – Outdoor Air Delivery Monitoring	1
IEQ Credit 1.3	Indoor Air Quality Best Management Practices – Increased Ventilation	1
IEQ Credit 1.4	Indoor Air Quality Best Management Practices – Reduce Particulates in Air Distribution	1
IEQ Credit 1.5	Indoor Air Quality Best Management Practices – Indoor Air Quality Management for Facility Additions and Operations	1
IEQ Credit 2.1	Occupant Comfort – Occupant Survey	1
IEQ Credit 2.2	Controllability of Systems – Lighting	1
IEQ Credit 2.3	Occupant Comfort – Thermal Comfort Monitoring	1
IEQ Credit 2.4	Daylight and Views	1
IEQ Credit 3.1	Green Cleaning – High-Performance Cleaning Program	1
IEQ Credit 3.2	Green Cleaning – Custodial Effectiveness Assessment	1
IEQ Credit 3.3	Green Cleaning – Purchase of Sustainable Cleaning Products and Materials	1
IEQ Credit 3.4	Green Cleaning – Sustainable Cleaning Equipment	1
IEQ Credit 3.5	Green Cleaning – Indoor Chemical and Pollutant Source Control	1
IEQ Credit 3.6	Green Cleaning - Indoor Integrated Pest Management	1
TOTAL		**15**

Table 6

Innovation in Operations Credits (USGBC, 2009)

Innovation in Operations Credit	Credit Description	Available Points
IO Credit 1	Innovation in Operations	1-4
IO Credit 2	LEED Accredited Professional	1
IO Credit 3	Documenting Sustainable Building Cost Impacts	1
TOTAL		**6**

Table 7

Regional Priority Credits (USGBC, 2009)

Regional Priority Credit	Credit Description	Available Points
RP Credit 1	Regional Priority	1-4
TOTAL		**4**

Various techniques are used in the assessment and application of sustainability principles when building and retrofitting facilities. These include life-cycle assessments, life-cycle costing, and charettes (Kibert, 2005, p.3). Additionally various tools are utilized to assist with project planning and design. These LEED-EB tools include the Energy Star program(s), eQuest energy modeling, LEED-Online, and American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) energy audits. Other tools that may be used by a LEED-EB team include construction project management programs such as Prolog. Construction project management tools such as financial management programs and subcontractor management software assist in the construction phase of the project. During the long term following major renovations and during operations, programs such as specialized computerized Environmental Management Systems can be used to track the long term impacts of the LEED-EB project.

Construction renovation and program development are both equally important on LEED-EB projects. Organizational change, paradigm shifts, attitudes and operational changes must be implemented. New methods of doing business and progressive ways of analyzing success and profitability are central to LEED-EB, in addition to the construction and physical facility changes that will be designed and modified.

The USGBC has created an entity to review and approve (or reject) the certification of LEED projects. This entity administers the certification process and is known as the Green Building Certification Institute (GBCI). An internet program called LEED Online is used to manage the documentation and submittal of all credits targeted. When a project successfully submits all of the required documentation a third party reviewer ensures that all of the necessary requirements were met and certifies the facility based on the number of points the facility achieved.

Under the LEED-EB program, buildings are certified and programs that have been implemented become the operative norm for the organization. LEED-EB requires a great paradigm shift in an organization because it requires significant change in methods and internal processes.

Organizations that may seek LEED-EB certification include large corporations such as Intel or small community buildings such as a Town Hall in rural Arizona. The range of projects, people and facilities that have transformed their company using LEED-EB is broad and far reaching. Organizations that have certified their facilities under the LEED-EB program to date include Recreational Equipment, Inc (REI), the Chicago Merchandise Mart, Whole Foods Market, various local, state and federal government facilities, Albertson's Supermarkets, Bank of America buildings, and the list goes on (USGBC, 2010). This indicates that regardless of the size of the facility, or the type of organization operating or occupying the facility, LEED-EB is achievable.

An Overview of Six Sigma

Six Sigma is a term used to describe a set of methods, tools, and strategies for implementing organization change to improve the bottom line and reduce defects in a manufacturing process. Simply put by Calia, et al (2009), "Six Sigma is a systematic method for process improvement focused on financial results that uses statistical and quality management tools", (p. 1303). Harry and Schroeder (2000) state that Six Sigma is "a disciplined method of using extremely rigorous data gathering and statistical analysis to pinpoint sources of errors and ways of eliminating them." It has been used by corporations such as General Electric (GE) and Motorola to implement organizational improvements.

In summary, the main objective of Six Sigma is to reduce defects and variability in manufacturing processes. Higher sigma values indicate improved processes and products. A product produced at a Six Sigma level is equivalent to 3.4 defects per million opportunities (DPMO). A sigma level 1 would provide 30.9% of the items without defects, sigma level 2 with 69.2% without defects, sigma level 3 with 93.3% without defects, sigma level 4 with 99.4% without defects, sigma level 5 with 99.98% without defects and a sigma level 6 (Six Sigma) with 99.9997 items without defects (Pheng and Hui, 2004, p.483). Put into other terms, a 1% error rate would be equal to 20,000 lost articles of mail every hour, 5,000 botched surgical procedures every week or four accidents per day at major airports (Chowdhury, 2001).

Six Sigma was developed at Motorola in the 1980's by an engineer named Bill Smith. Mikel Harry, a friend and co-worker of Bill Smith, was also one of the early pioneers of Six Sigma. Mr. Harry carried the program to other corporations and helped them to transform their companies by implementing Six Sigma principles and methodologies. Within a decade the Six Sigma mindset had traveled across the globe and eventually ended up in the hands of Jack Welch (CEO of General Electric) and Larry Bossidy (CEO of AlliedSignal). Both General Electric (GE) and AlliedSignal utilized Six Sigma as an approach for reducing process lead times and variation, thereby improving a company's performance (Snee, 2010, p. 10; Pheng and Hui, 2010, p. 482). In fact, GE CEO Jack Welch is quoted as saying about Six Sigma, "[It was] the most important initiative GE has ever undertaken" (George, 2002, p. ix). Six Sigma spread across the United States and eventually became an international approach for improving business processes and the bottom line.

Lean Six Sigma is the most recent development to improvement approaches. This approach combined the efficiencies of Lean Production with the cost and quality tools of Six Sigma (Snee, 2010, p. 10).

Snee (2010) states:

Adding lean concepts, methods and tools to Six Sigma strengthened the approach in the areas where improvements could be identified and implemented quickly (one to four weeks), many of which involved the flow of information and materials through a process. Today Lean Six Sigma is the improvement approach of choice. (p. 10)

This research covers an analysis of how Six Sigma and/or Lean Six Sigma methods could be combined with LEED-EB to improve the implementation of corporate sustainability initiatives, reduce the time required to implement the changes, and provide an opportunity for adding value for stakeholders. For purposes of this research, the terms Lean Six Sigma and Six Sigma will be used interchangeably. The reason for this is the Six Sigma and Lean programs have merged so successfully that they are pretty much one in the same today. "Lean Six Sigma is a business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom line results" (Snee, 2010, p.10). Interestingly Lean Six Sigma has also proven be beneficial to corporations in providing a laboratory for developing future leaders. Leaders who are able to make great paradigm shifts in the organization and enable great change, bring vision for the future success of an organization.

Six Sigma has benefitted organizations by providing a methodology for making improvements and solving problems. It is important to note that Six Sigma is focused on bottom line results. These are the figures that get the attention of top leadership. Six Sigma combines a human aspect with a process aspect. Snee (2010) developed a table of important considerations for Lean Six Sigma as shown in Table 8 (p. 11). One Six Sigma project alone can save a company $50 thousand to $175 thousand dollars. The cost of developing and implementing a full scale Six Sigma program typically pays for itself in six to 12 months. The new process or program enables continued savings which can accumulate year after year in many cases (Snee, 2010, p. 12).

Table 8

Human and Process Aspects of Lean Six Sigma Approach (Snee, 2010, p.12)

Human Issues	Process Issues
Bottom Line Focus ($) Management Leadership Sense of Urgency Customer Focus Project Teams Culture Change	Process Improvements Analysis of Variation Disciplined Approach Quantitative Measures Statistical Thinking and Methods Process Management

How does Six Sigma work?

Six Sigma has a very well defined definition of roles and responsibilities for a project. There are Six Sigma experts, otherwise known as “Black Belts”, who are responsible for leading a project and statistically validating independent and dependent variables. “Champions” for a Six Sigma project are responsible for removing organizational barriers. Green Belts are trained to lead less complex Six Sigma projects. A diagram showing the Six Sigma organizational structure is provided in Figure 3 (Calia, et al., 2009, p. 1305).

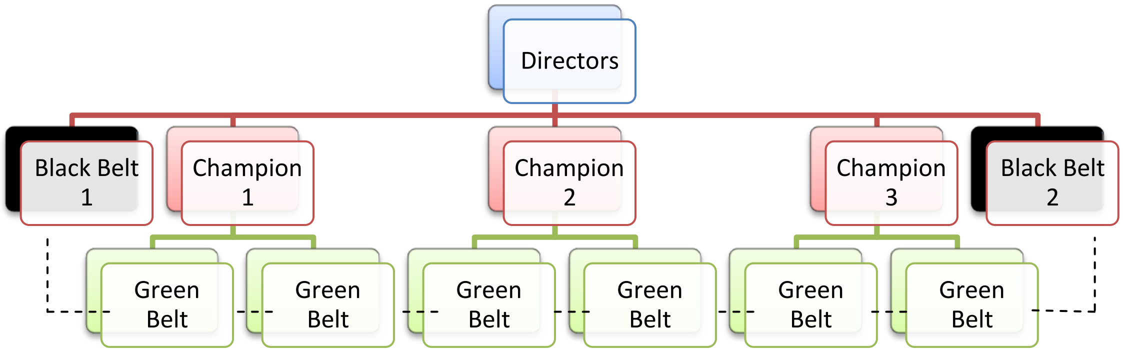

Figure 3. The Six Sigma organizational structure (Snee, et al., 2009, p. 1305).

Michael L. George (2002) states that "more organizations fail from a lack of creating the right culture and infrastructure than from using the wrong tools" (p. 24). George continues, Six Sigma is not "just a bag of tools", organizations need to have management engagement, resource commitment, and execution infrastructure (or hierarchy of roles). An organization's "source of power is first and foremost in the culture" (George, 2002, p.24). Additionally, George goes on to say "It is my contention that the culture of Six Sigma is the reason for its success…most efforts succeed or fail based on execution; few fail for a lack of a good strategy. Six Sigma provides the cultural framework to covert strategy into good execution" (2002, p. 32).

Per George (2002, p. 32), the key messages of Six Sigma are:

1. The infrastructure for cultural change is the most powerful contribution of Six Sigma.

2. Decisions about which projects to pursue must be based at least in part on the potential impact on net present value.
3. Sustained improvement is possible only with management engagement.
4. CEO goals are translated to frontline projects and coordinated through an organization of people and technical resources.
5. A standard problem-solving process and associated tool set provides the means for basing decisions on data.

One of the first and perhaps the most essential is the use of the DMAIC (da-may-ick) process. DMAIC stands for Define-Measure-Analyze-Improve-Control. W. Edwards Demming developed DMAIC to assist businesses in implementing process quality controls. Six Sigma is powered by DMAIC and its process improvement tools. Many statistical analysis and team management tools are associated to the various phases of the DMAIC process. George (2002, p.25) describes each of these phases in DMAIC and the associated tools. Figure 4 provides a summary of each of these phases. Table 9 lists the major steps and tools frequently used by Six Sigma teams when running a project (George, 2002).

Figure 4. The DMAIC process (George, 2002, p. 25).

Table 9

DMAIC Steps and Associated Tools (George, 2002)

Process	Activity	Tools Used for Lean Six Sigma	
Define	1. Establish Team Charter 2. Identify Sponsor and Team Resources 3. Administer Pre-Work	• Project ID Tools • Project Definition Form • NPV/IRR/DCF Analysis	• PIP Management Process • SSPI Toolkit
Measure	4. Confirm Team Goal 5. Define Current State 6. Collect and Display Data	• SSPI Toolkit • Process Mapping • Value Analysis • Brainstorming • Voting Techniques • Pareto Charts • Affinity/ID	• C&E/Fishbones • FMEA • Check Sheets • Run Charts • Control Charts • Gage R&R
Analyze	7. Determine Process Capability and Speed 8. Determine Sources of Variation and Time Bottlenecks	• C_p and C_{pk} • Supply Chain Accelerator Time Trap Analysis • Multi-Vari • Box Plots • Marginal Plots • Interactive Plots	• Regression • ANOVA • C&E Matrices • FMEA • Problem Definition Forms • Opportunity Maps
Improve	9. Generate Ideas 10. Conduct Experiments 11. Create Straw Models 12. Conduct B's and C's 13. Develop Action Plans 14. Implement	• Brainstorming • Pull Systems • Setup Reduction • TPM • Process Flow • Benchmarking • Affinity/ID • DOE • Gantt Charts	• Hypothesis Testing • Process Mapping • B's and C's/Force Field • Tree Diagram • Pert/CPM • PDPC/FMEA
Control	15. Develop Control Plan 16. Monitor Performance 17. Mistake-Proof Process	• Check Sheets • Run Charts • Histograms • Scatter Diagrams • Control Charts	• Pareto Charts • Interactive Reviews • Poka-Yoke

The Six Sigma culture states that 1% to 3% of personnel need to be dedicated to a project on a full time basis. These personnel need to have CEO and top management engagement, with resources available to achieve goals. Coaching and training or project prioritization is required. A focus needs to be on the return on investment of the projects rather than the cost of the program (George, 2002).

Six Sigma in Industry

Han, et. al. (2008) described two case studies that were performed in order to analyze the impact of utilizing Six Sigma methods to initiate performance improvements and increased quality in the construction industry. This study focused on the general methods and tools used to apply the Six Sigma principles as an approach for improving construction performance. Han, et al. (2008) state that the construction industry lacks the "methodological metrics to quantitatively set out the definite goal of improvements and reduce the process variability through the evaluation of quality level in the current construction operations" (p. 30).

The case study performed by Han, et al. (2008), focuses on cycle time variation on construction projects. For instance, it was determined, through the use of Six Sigma methodologies, that 20 tons of iron bars should be kept in stock to prevent a significant impact to cycle time variation. Six Sigma methodologies were reported to improve the quality level, particularly when the processes were complicated and extended. They discovered that Six Sigma was not just a management tool for productivity and quality, but also a quality and process control tool that could be used by the construction industry (Han, et al., 2008, p. 30).

Pheng and Hui (2004) studied Six Sigma as a quality initiative that could be applied to the building industry. They performed a case study on impact of Six Sigma on three pilot projects performed by the Housing and Development Board (HDB) in Singapore. The HDB is a statutory board under the Singapore Ministry of National Development and has the function of improving the affordability and quality of public housing. The Building and Development division of the HDB was very interested in the idea of implementing Six Sigma in their group in order to increase the level of quality they were producing. They implemented Six Sigma by creating task force and then training these 10 key members. These individuals attended 4 weeks of training to become Six Sigma Black Belts who in turn carried the message back to the senior management and Champions. The Black Belts then conducted in-house training in order to develop the Green Belts. Note that Six Sigma is typically used in the industries of manufacturing, health care and service industries. Thus, finding information on how to utilize Six Sigma principles in the building industry had to be developed by Master Black Belts before this project could proceed. The Master Black Belts provided examples to the task force regarding how the Six Sigma tools could be used in the building industry (Pheng and Hui, 2004, pp. 484-485). A similar analysis is performed in this these to determine how Six Sigma tools are used on a LEED-EB project.

In the Pheng and Hui (2004) study, Six Sigma was used to improve the quality of the building product, the mechanical systems of the apartments and to reduce transactional service time. In order to calculate the quality of the construction process, the task force determined that the Construction Quality Assessment System (CONQUAS) would be used to score items such as the quality of internal finishes, roofs, external walls, etc. Once these areas were scored, the team had a baseline and could then set the benchmark and develop goals. The results of the CONQUAS indicated that the number defects in the internal finishes for example was 2.66 sigma, which is the equivalent of only 77.39% in good standing. Management determined that at least a 3.8 sigma should be the goal, which would increase the quality level to 99%. Using Six Sigma methods and tools, the team was able to increase the quality from 2.66 sigma to 3.95 sigma, which is more than the goal they had originally set. Therefore, Six Sigma proved to be a beneficial method for improving this project (Pheng and Hui, 2004, pp. 486-489).

In a study performed by Calia, et al (2009), Six Sigma was analyzed to determine the impact it would have on the performance of a Pollution Prevention program. A Pollution Prevention program is an environmental management system that increases efficiencies related to the consumption of materials, energy, water and other resources. This program is mainly implemented as a means of saving money rather than as a means of ensuring compliance with environmental regulations. The Pollution Prevention / Six Sigma study is a good reference for this thesis, due to the fact that Pollution Prevention involves the reduction of pollution within a process, and making great organizational changes in order to achieve such results (Calia, 2009, p. 1304).

Implementing a Pollution Prevention program faces many challenges. As reported by Calia, et al. (2009) there are many obstacles preventing success (p. 1304). Similar issues may impact a LEED-EB project as implementing a Pollution Prevention program and LEED-EB have a number of similarities. According to Calia, et al. (2009), the organizational barriers of a Pollution Prevention program include:

- Insufficient decision-makers support to Pollution Prevention
- Organizational structures separating environmental decisions
- Lack of clarity about who should take on the leadership role in projects
- Resistance to change
- Insufficient employee accountability mechanisms
- Reward system not focused on Pollution Prevention
- Fear that a Pollution Prevention project may jeopardize product quality

- Lack of information to recognize an opportunity for waste reduction
- Insufficient infra-structure to support Pollution Prevention plans
- Poor internal communication
- Conflicts and resistance to change
- Inflexible organizational structure
- Limited financial resources for capital improvements
- Insufficient availability of time and personnel
- Concern that manufacture process change negatively impact quality
- Concern of negative customers' perception about the product
- Fear that the stability of the production system may be negatively changed by the Pollution Prevention project

Calia, et al. (2009) performed a comparative analysis of a Pollution Prevention program before and after the implementation of Six Sigma. The study was performed over the course of 12 years (six years prior to Six Sigma implementation and six years following). The research showed that prior to utilizing Six Sigma as a method of implementing a Pollution Prevention program, 82,769 tons per six years of pollution we prevented, whereas after applying Six Sigma the amount of pollution prevented totaled 133,864 tons per six years. That is an increase of 62% more pollution prevented with the use of Six Sigma tools and methods. With the use of Six Sigma, more pollution prevention projects were able to occur. In the six years prior to applying Six Sigma, 256 Pollution Prevention Projects occurred whereas following Six Sigma inclusion, 1775 Pollution Prevention projects took place. That is an increase of nearly 700% (Calia, et al., 2009, pp. 1306-1307).

Calia, et al. (2009) has a strong case for supporting Six Sigma as a use for a Pollution Prevention program. The qualitative analysis performed by Calia, et al. (2009) explains how the Pollution Prevention program interacts with Six Sigma. The project implemented the organizational structure and methodology of Six Sigma. The authors state that more projects were submitted for the Pollution Prevention program due to the fact that Six Sigma allowed for the implementation "due to the new organization capacity for managing projects based on precise data analysis" (Calia, et al., 2009, p. 1308). They continue to explain how more projects were submitted and add that it was due to the following keys that Six Sigma brought to the table:

1. An organizational culture for project management
2. Defining an organizational structure with exclusive roles for project management directors and managers
3. Training most employees in the Six Sigma methodology
4. Yearly defining and allocating cost reduction goals
5. Designing a leader and a team to each project

6. Evaluating employee performance as project leaders and as members in project teams
7. Promoting successful project managers to special career opportunities

Calia, et al. (2009) briefly discusses the use of statistical analysis at the start of the paper, but they do not list it as a significant cause for the increased pollution prevention totals. They mostly cover the soft skills associated with Six Sigma.

CHAPTER 3 METHODOLOGY

A Description of the General Methodology

The question of day was proposed by George (2002) when he asked, "How can we bring Lean and Six Sigma together into an effective strategy for creating shareholder value?" (p. 61). This thesis poses a similar question. How can industry bring LEED-EB and Six Sigma together into an effective strategy for creating shareholder value, environmental benefits and corporate sustainability? Is this a possibility?

The purpose of this thesis is to understand if Six Sigma methodologies and tools can be aligned with the requirements and processes of a LEED-EB project. In order to accomplish this research goal, it is necessary to validate qualitatively if a synergy is possible and to explain how the Six Sigma methodology interacts with the LEED-EB program.

The Research Context

The research conducted in this thesis is of a qualitative fashion. Charts, graphs and checklists are examples of what a project might utilize in order to implement Six Sigma methods and strategies on a LEED-EB project.

A Summary Statement of the Methodology

The objective of this research is to understand how Six Sigma methodologies could interact with LEED-EB. Research was conducted to determine how Six Sigma might interact with LEED-EB program.

The analysis utilizes knowledge and experience gained from managing previous LEED-EB projects. A new LEED-EB program management roadmap is created by combing the Six Sigma methodologies with a LEED-EB program, indicating which tools and practices can be utilized along each step of the way.

Templates, flow charts, and excel spreadsheets as well as the use of statistical analysis tools are created and evaluated for compatibility between Six Sigma and LEED-EB. The human process required for a successful Six Sigma project as described by Snee (2010) is also included in the analysis and program development.

The anticipated outcome of this research is to determine if a repeatable program, process or roadmap could be successfully developed. This roadmap includes the requirements of a LEED-EB project and the methods of a Six Sigma project.

CHAPTER 4 RESULTS

An Overview

The qualitative analysis aims to validate the following hypothesis: Six Sigma can successfully be applied to a LEED-EB project. This is addressed through the following systematic analysis of how the two programs can interact with one another.

In order to determine whether or not a Six Sigma approach can be applied to a LEED-EB project, this thesis analyzes what a Six Sigma project would require, and then determines how it might apply to LEED-EB. Through this process, a Six Sigma LEED-EB program was developed.

Recall that per George (2002, p. 32), the key messages of Six Sigma are:

1. The infrastructure for cultural change is the most powerful contribution of Six Sigma.
2. Decisions about which projects to pursue must be based at least in part on the potential impact on net present value.
3. Sustained improvement is possible only with management engagement.
4. CEO goals are translated to frontline projects and coordinated through an organization of people and technical resources.
5. A standard problem-solving process and associated tool set provides the means for basing decisions on data.

To ensure that these five key messages of Six Sigma are incorporated into a Six Sigma LEED-EB program, the key messages are divided into two phases or two parts – The Foundation and The Process. Messages one, three and four are a part of the foundation. With a successful foundation, messages two, three and five, the Process, can be built with the support that it will need to be successful. This is further illustrated below.

The LEED-EB project that was performed in Phoenix, AZ that was unsuccessful in launching was missing this foundational step required by Part 1. Upper management was interested, but there was no support. A team was created consisting of two people, who were still required to handle their regular work, and try and market and sell work at the same time. They were not given the opportunity to focus completely on a LEED-EB project for their company. An examination of how Part 1 – The Foundation could benefit a LEED-EB project is discussed in further detail in the next section.

Part 1 - The Foundation

Executive leadership and commitment.

George (2002) states that “the most important element is…executive support and engagement” (p. 62). He continues to state that an organization’s culture will make all the difference in the success of a Six Sigma project. Additionally, the Six Sigma LEED-EB program must impact the whole business, not just pockets in order to improve shareholder value and the CEO's engagement is necessary for that to occur. Some ways to ensure that the Six Sigma LEED-EB program includes this support is to have them commit 1% to 3% of personnel full time to the project (George, 2002, p. 62-63).

Another way the executive engagement and commitment can occur is through the development of a company policy stating the goals of the project. Snee and Hoerl (2003) state the development of a strategy with clear goals and objectives is central ensuring that leadership is committed (p. 48). With a clear goals statement, the Six Sigma LEED-EB team can focus on what matters most throughout the future phases of the work. With a clear policy statement, the team can always return to the vision of what is important to the company.

Culture.

A Six Sigma LEED-EB program should include a way to help organizations modify their culture. People typically have a difficult time with change and resistance is inevitable. For a project such as LEED-EB or Six Sigma, it is important to ensure that all of the stakeholders involved are willing and committed (Burge, 2008, p. 36). The program will require changes to many aspects of business. From the types of products purchased to a decision of a long term investment in photovoltaics, the culture of the organization needs to support these types of decisions and the follow through that will be required to install, maintain and operate such equipment. Burge (2008), states that there are four main communicative parts to shore up a willingness to change. These parts include:

1. Provide stakeholders (process owners, workers, managers, executives, suppliers, etc.) with a full and clear understanding of the process, the intent of the project and the potential outcome.
2. Ease the fear of change. It can include fear of losing a job as a result of improved process performance, fear of being moved to another area or even fear of receiving a reduction in compensation.
3. Create, maintain and promote an effective and easy-to-use system for communication such as daily/weekly reports, breakthrough meetings or information boards.
4. Promote an environment where all stakeholders can share their ideas and receive feedback throughout the project life cycle.

In order to make a change in culture, an organization needs have data regarding their baseline. They would then determine what changes they would have to make to get desired results. It may require the development of a company sustainability team or hiring a full time sustainability officer to monitor and track sustainability initiatives as a full time job.

A Six Sigma team supports change and ensures success. This team is comprised of professionals known as Black Belts, Green Belts, project team members, Master Black Belts, project sponsors, Champions, Directors, Executive Business Unit Leadership, etc. This method can be combined with the LEED-EB work by creating a team of experts to support the LEED categories such as Mechanical, Electrical, Plumbing, Energy, and Renewable Energy. These experts could become the Six Sigma LEED-EB Green Belts. The Sustainability experts could become the Sustainability Black Belts and would serve to provide support related to the requirements of LEED and sustainability measures on a whole. The Black Belts would likely be the LEED APs since they are required to have more experience and knowledge of the LEED-EB program. Figure 5 describes the relationship between the key players on a Six Sigma LEED-EB Team.

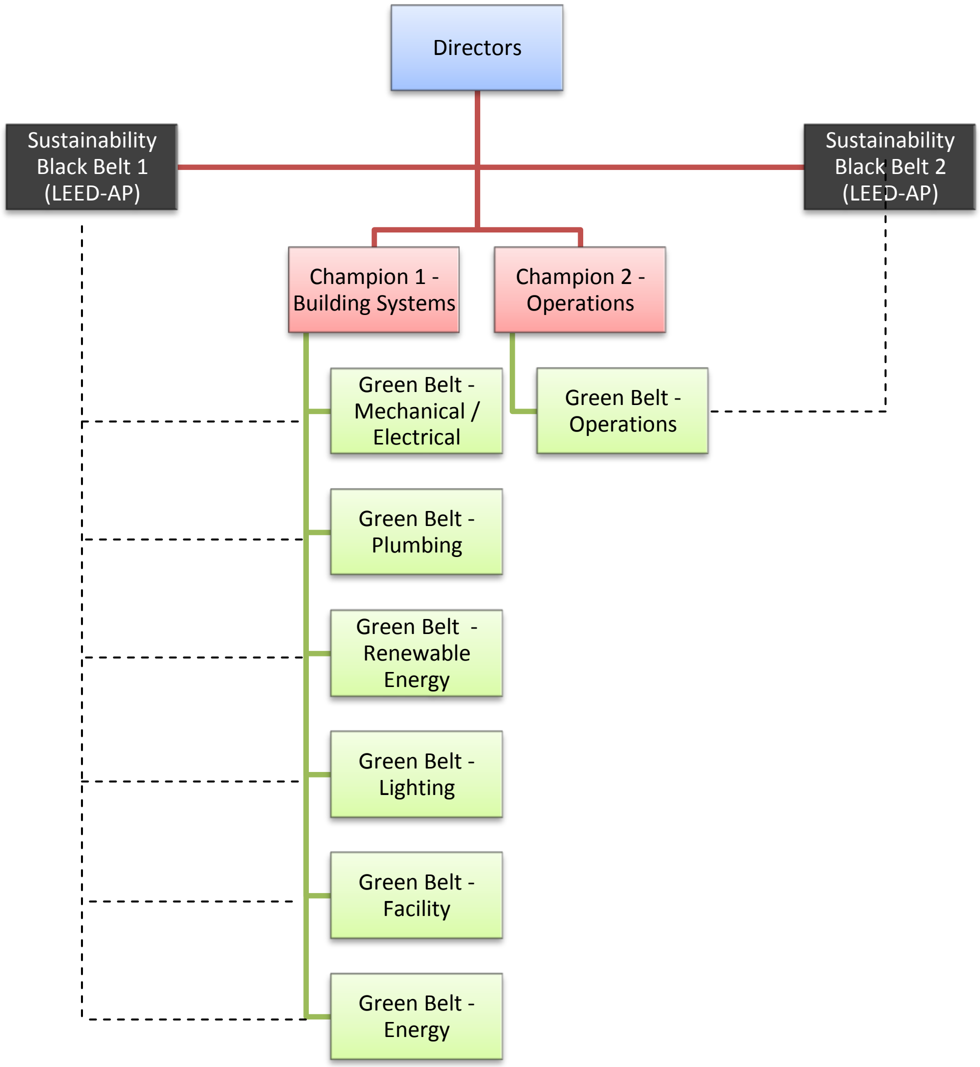

Figure 5. Six Sigma LEED-EB program team.

Part 2 – The Process

Within Part 2 – The Process, we need to further break down the phases and steps required to complete a LEED-EB project and describe how we can apply Six Sigma principles along the way. This is where the sustainability ideas and vision becomes action. In Six Sigma, the DMAIC model is used to put those ideas into action.

A typical LEED-EB program might follow the standard design, construction, operation and maintenance model that most construction projects would follow. However, it is important to remember that LEED-EB is not all about construction. In fact, if we breakdown the number of points that are available under the LEED program, we see that a significant amount of the work involved with a LEED-EB project involves implementing organizational change through plan development. Table 10 shows the breakdown of each of these points based on four types of work involved. These types of work include the following:

1. Prepare Plans and Conduct Studies
2. Design and Construction
3. Combination of Plan Development and Design and Construction
4. LEED Accredited Professional

Table 10

LEED-EB Point Distribution of Work Type

	Prepare Plans and Conduct Studies	Design and Construction (D&C)	Combination of Plans, Studies and D&C	LEED AP	Total Points Per Category
Sustainable Sites	6	4	16	0	26
Water Efficiency	0	7	7	0	14
Energy and Atmosphere	5	8	22	0	35
Materials and Resources	8	0	2	0	10
Indoor Environmental Quality	9	3	3	0	15
Innovation in Operations / Regional Priority	3	3	3	1	10
Total Points Per Type of Work	31	25	53	1	110

It should be noted that the Innovation in Operations and Regional Priority points are evenly distributed across the work types, due to the fact that those projects are not standard requirements, but rather open to the organization to determine what they would like to try to get a point for. Additionally, it is important to note that all points will require some level of study in order to accomplish the project goals. Some credits require that study results be provided in order to receive the credit. In those circumstances, for the purpose of this analysis, the work type in Table 10 that refers to conducting studies involves only those credits that the USGBC wants to receive documentation of that study.

When we look at the percentage breakdown of the total points available, we see that 28% of the points are associated with developing plans and conducting studies without any actual construction involved.

Additionally, 23% require some form of design and construction, 48% of the points require a combination of construction, plans and studies and the remaining 1% is for having a LEED AP on the project (Figure 6). For the purpose of this evaluation, "Design and Construction" was defined as the design and installation of any material including landscaping, furniture, lighting, as well as actual building construction.

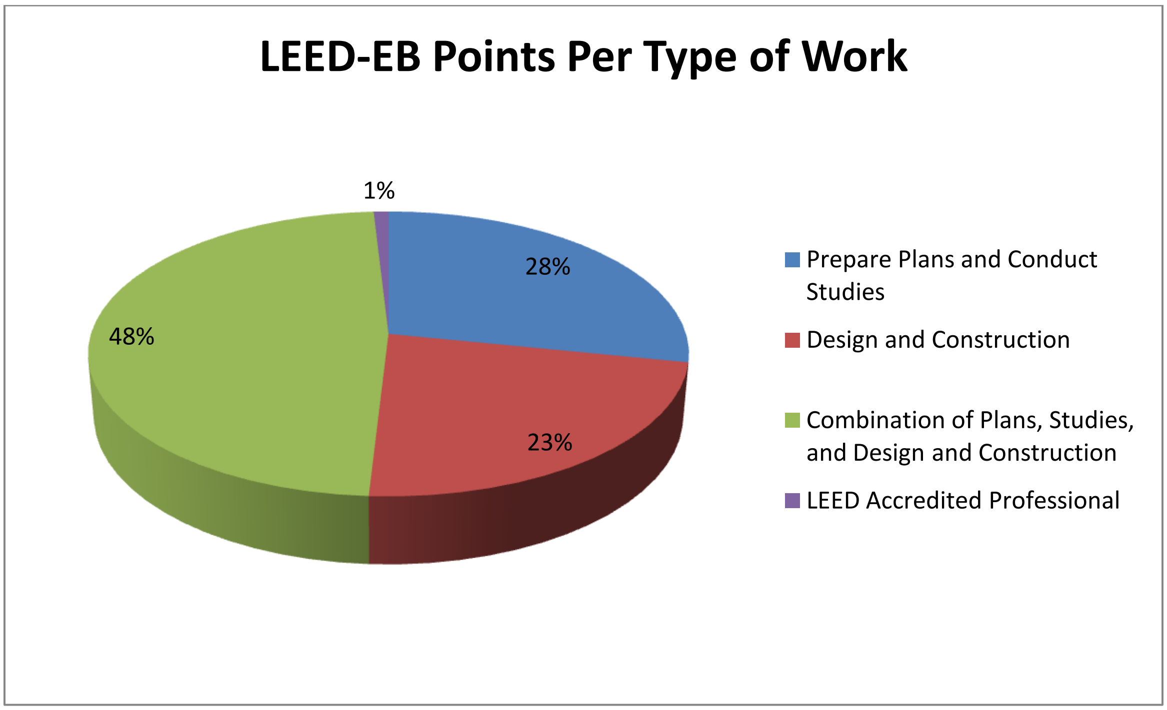

Figure 6. Percentage of LEED-EB points associated with four work categories.

Knowing what kind of work we are dealing with from the start, enables an improved method for team development during Part 1 – Foundation, because leaders and choose team members based on the strengths of various individuals in the organization and assign them to the areas where they are needed most.

Also, having knowledge of the work types will assist the team during Part 2 – The Process to divide work. But we need to know what work to divide. We still need to select the projects that will help the organization achieve LEED-EB certification.

A construction project typically involves a design phase, a construction phase, and finally an operations and maintenance phase. Due to the fact that LEED-EB is not a typical construction project, we might want to add some additional phases to include the following: evaluation, design, construction/implementation, performance period, certification, and ongoing operations and maintenance (Figure 7). This could be represented in a cycle to show how the goal of LEED-EB is to support continuous improvement.

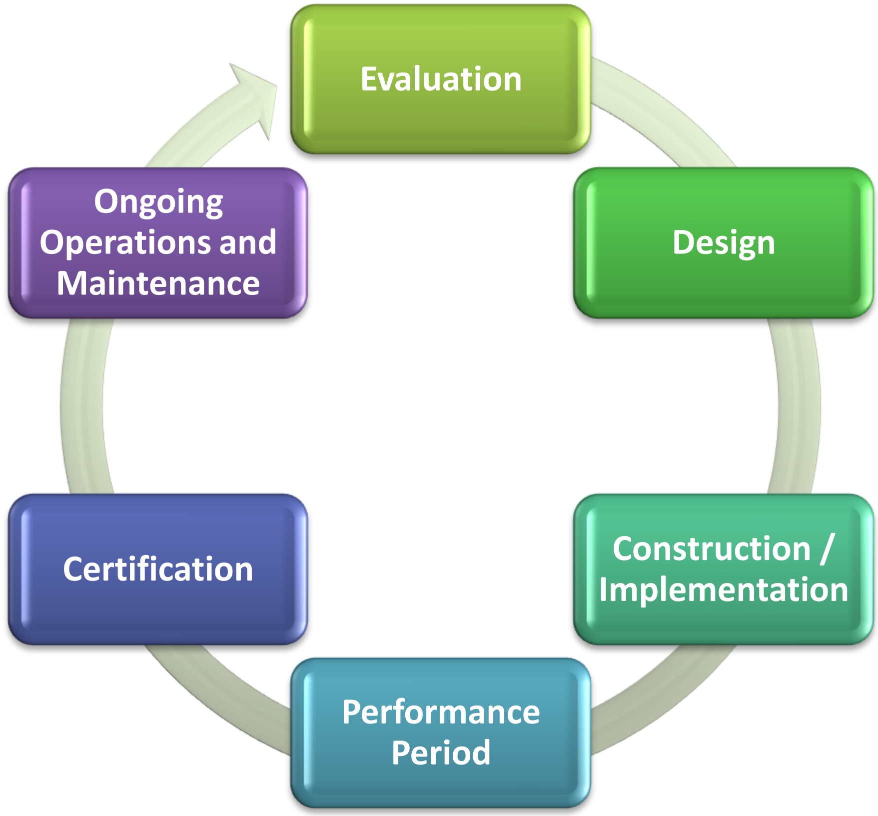

Figure 7. Phases of a LEED-EB process.

The next question is, how do these LEED-EB Phases align with the Six Sigma methods seen in DMAIC? In Table 11, we see how the phases of LEED-EB line up with the phases of Six Sigma or the DMAIC process. When we take it one step further and merge the two into one program, we create a DMAIC for LEED-EB model (Table 12).

In Table 12, the phases for LEED-EB have been illustrated alongside the DMAIC model to lay out how they may fit together. Notice how many DMAIC steps go by during the evaluation phase of the LEED-EB process. DMAIC is a better model because it provides a more defined explanation of everything that would be required to complete an evaluation. Therefore, if we combine the two programs using the DMAIC model as the new backdrop for each of the steps, we arrive at the model shown in Table 12.

Table 11.
Six Sigma / LEED-EB Process Alignment

Six Sigma Process	Six Sigma Activity	LEED-EB Process	LEED-EB Activity
Define	1. Establish Team Charter 2. Identify Sponsor and Team Resources 3. Administer Pre-Work	**Evaluation** ↓	1. Form a team 2. Determine LEED-EB Goals
Measure	4. Confirm Team Goal 5. Define Current State 6. Collect and Display Data		3. Collect Baseline Data
Analyze	7. Determine Process Capability and Speed 8. Determine Sources of Variation and Time Bottlenecks		4. Compare baseline data to LEED-EB requirements 5. Brainstorm ideas for earning credits 6. Perform cost/benefit analysis
Improve	9. Generate Ideas 10. Conduct Experiments 11. Create Straw Models 12. Conduct B's and C's 13. Develop Action Plans 14. Implement	**Design** **Construction/ Implementation**	7. Select projects 8. Begin Construction / Implementation
Control	15. Develop Control Plan 16. Monitor Performance 17. Mistake-Proof Process	**Performance Period** **Certification** **Operation and Maintenance**	9. 12 Months of Performance Monitoring 10. Prepare and submit all required documentation 11. Operate and Maintain

Table 12.
The New Six Sigma LEED-EB DMAIC Model

Six Sigma LEED-EB Process	Six Sigma LEED-EB Activity
Define	1. Establish Team Charter 2. Identify Sponsor and Team Resources 3. Administer Pre-Work 4. Determine LEED-EB Goals
Measure	5. Confirm Team Goal 6. Define Current State 7. Collect and Display Data
Analyze	8. Determine Capability for LEED-EB Credits 9. Determine Sources of Variation and Time Bottlenecks
Improve	10. Generate Ideas 11. Conduct Experiments 12. Create Straw Models 13. Conduct B's and C's 14. Perform Cost / Benefit Analysis 15. Develop Action Plans / Select Projects 16. Implement & Construct
Control	17. Develop Control Plan 18. Monitor Performance (12 Months) 19. Prepare and Submit Documentation for Certification 20. Mistake-Proof Process 21. Operate and Maintain

The Six Sigma Tools.

If we are able to utilize the strength of the DAMAIC model to run a LEED-EB project, are we also able to utilize the Six Sigma tools that are associated to each of the DMAIC phases? Recall that the tools associated with the DMAIC model are numerous. Which tools apply to the work required for a Six Sigma LEED-EB Project? By merging the LEED-EB document into the DAMAIC one, we are ready to align the associated Six

Sigma tools. For the purpose of this research, the Six Sigma tools that are most commonly used based on the writings of George (2002) will be assessed.

Table 13 lists the tools used in a Six Sigma program. In the following research we will gain an understanding of a selection of the main Six Sigma tools (as indicated by George, 2002). Following an explanation of how the tool is used in a Six Sigma project, analysis of whether the tool could be used by a LEED-EB program is provided. If the tool is compatible with a LEED-EB program, an example for how the tool might be used in the particular phase of the LEED-EB program is provided.

Table 13
Six Sigma Tools Used for Each Stage of the DMAIC Process.

Process	Tools Used for Lean Six Sigma	
Define	• Project ID Tools • Project Definition Form • NPV/IRR/DCF Analysis	• PIP Management Process • SSPI Toolkit
Measure	• SSPI Toolkit • Process Mapping • Value Analysis • Brainstorming • Voting Techniques • Pareto Charts • Affinity/ID	• C&E/Fishbones • FMEA • Check Sheets • Run Charts • Control Charts • Gage R&R
Analyze	• C_p and C_{pk} • Supply Chain Accelerator Time Trap Analysis • Multi-Vari • Box Plots • Marginal Plots • Interactive Plots	• Regression • ANOVA • C&E Matrices • FMEA • Problem Definition Forms • Opportunity Maps
Improve	• Brainstorming • Pull Systems • Setup Reduction • TPM • Process Flow • Benchmarking • Affinity/ID • DOE • Gantt Charts	• Hypothesis Testing • Process Mapping • B's and C's/Force Field • Tree Diagram • Pert/CPM • PDPC/FMEA
Control	• Check Sheets • Run Charts • Histograms • Scatter Diagrams • Control Charts	• Pareto Charts • Interactive Reviews • Poka-Yoke

Define phase.

The activities of the Define phase are:

1. Establish Team Charter
2. Identify Sponsor and Team Resources
3. Administer Pre-Work
4. Determine LEED-EB Goals

Recall that the teams have already been selected during Part 1 – The Foundation. Now that we are working on Part 2 – The Process, using the DMAIC LEED-EB Model, we need to develop a clear understanding of the aims and principles of the group. The team will develop a purpose statement which would point to the most important reason(s) for pursuing a LEED-EB project. Some options might include: 1. Save money, 2. Improve public image, 3. Reduce impact on the environment, 4. Meet requirements of customers only working with sustainable corporations (this is frequently a requirement of government agencies and universities) or 5. Improve indoor environmental quality of an older building where building occupants are sick. There are a myriad of reasons that a corporation would want to seek LEED-EB certification. The Team Charter developed for the LEED-EB project will be based on those reasons utilizing the vision and overarching goals from top leadership.

The following summary describes the most commonly used Define Tools and how each one of them is used during the Define phase. If the tool is compatible with LEED-EB goals, an example of how a LEED-EB program could incorporate the Six Sigma tool is included.

Project Definition Form.

Project Definition Form Tools translate the opportunity discovered under the Project ID Tool into actual projects. Brainstorming exercises are held to challenge people to identify manageable pieces of the larger idea. The ideas are then sorted and screened. It is often beneficial to rank the project ideas as High, Medium or Low. A Project Definition Form should include the following elements: Problem Statement, Project scope, Background information, Key measures, Benefits, Effort, Assumptions, Risks/accelerators, Resource requirements, and Project duration/timeline (George, 2002).

Example:

A LEED-EB project checklist could be created to track which credits are being targeted. USGBC has created a checklist to assist teams. These premade checklists can be found at www.usgbc.org (Appendix 1). The LEED Online Tool located at www.gbci.org, must be used to register for certification and it also benefits the LEED-EB program by providing a method for tracking the credits that the team will be targeting and providing a shared location for project deliverables. Additionally, assignments to team members are entered here.

Net Present Value.

The Net Present Value tool relates potential projects to shareholder value. In LEED-EB, the most significant impact to improving shareholder value is through energy efficiency upgrades. The following example could help a company determine if they want to pursue energy efficiency retrofits based on the value that the company will gain from the retrofit. Example:

A facility spending $2/sq ft per year on energy with a 10% reduction in energy consumption based on square footage and cap rates has a potential to increase asset value (Table 14, Figure 8). These equations are found on the Energy Star website (www.energystar.gov). Online tutorials provide useful information to assist those interested in learning more about methods for communicating the value of energy efficiency retrofits.

$$\text{Cap Rate} = \text{Net Operating Income} / \text{Market Value} \qquad (1)$$

$$\text{Asset Value} = \text{Net Operating Income} / \text{Cap Rate} \qquad (2)$$

$$\text{Asset Value Increase} = \text{Net Operating Income Increase} \qquad (3)$$

Table 14

Asset Value Increase Due to Energy Efficiency Upgrades

Cap Rate	Building Size (Sq. Ft.)					
	50,000	100,000	200,000	400,000	800,000	1,600,000
5%	$200,000	$400,000	$800,000	$1,600,000	$3,200,000	$6,400,000
7%	$142,857	$285,222	$571,429	$1,142,857	$2,285,714	$4,571,429
9%	$111,111	$222,222	$444,444	$888,889	$1,777,778	$3,555,556

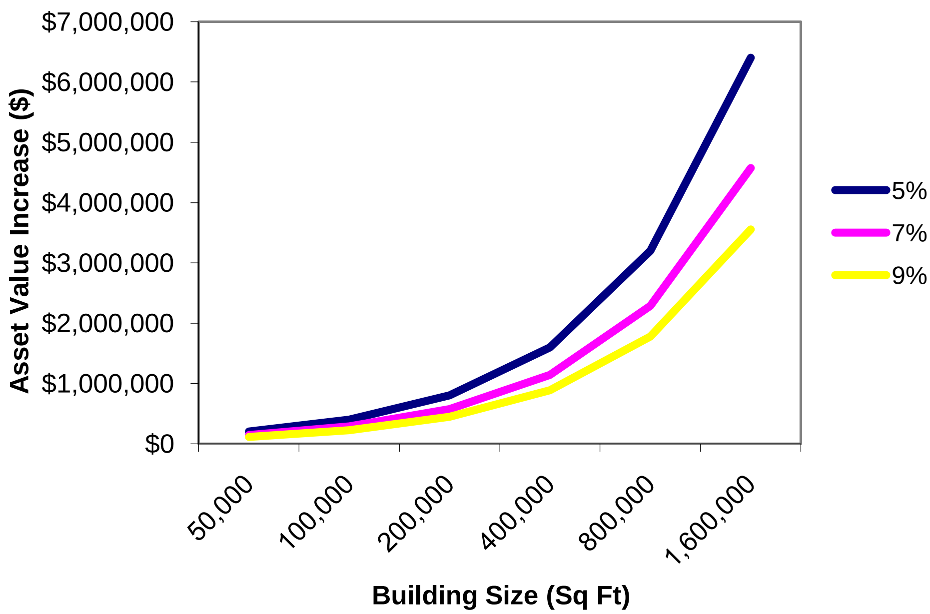

Figure 8. Energy efficiency retrofits in terms of shareholder value.

PIP Management Process.

A Performance Improvement Process (PIP) is a plan that leadership develops which includes big picture goals for the organization.

Example:

For LEED-EB, a PIP might be to increase the recycling rate company-wide to 90%. It may not state exactly how they are going to get there, but the organization is now clued that recycling is a major goal. This would enable participants to be empowered in generating ideas to reach this goal.

Systems and Software Process Improvement (SSPI) Toolkit.

Software programs can be used to implement, manage, and monitor projects.

Example:

LEED Online provides a limited role in project planning. I have not found a specific software program for LEED, but feel that this is certainly an area for future development and exploration. Some companies use software to manage goals through an Environmental Management System (EMS). This application could be used to assist with implementing the LEED-EB projects. Additional research on the similarities of an EMS and LEED-EB deserves some attention.

Suppliers, Inputs, Process, Output Customers (SIPOC).

SIPOC is one of the most important tools of Six Sigma. SIPOC is used to take a process view of how the company performs a specific function. The SIPOC diagram is used to quickly map all of these players (Figure 9).

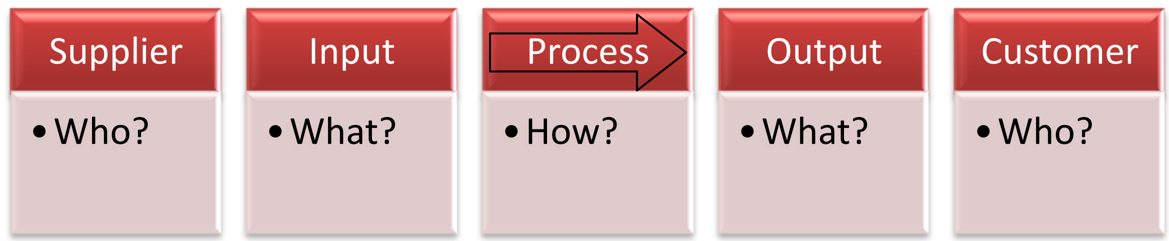

Figure 9. SIPOC diagram.

Example:

SIPOC could be used in a LEED-EB project in a variety of ways. One very simple example is to create a SIPOC office supply purchasing map which will eventually be used in future phases of the DMAIC process to plan and implement a green purchasing program (Figure 10).

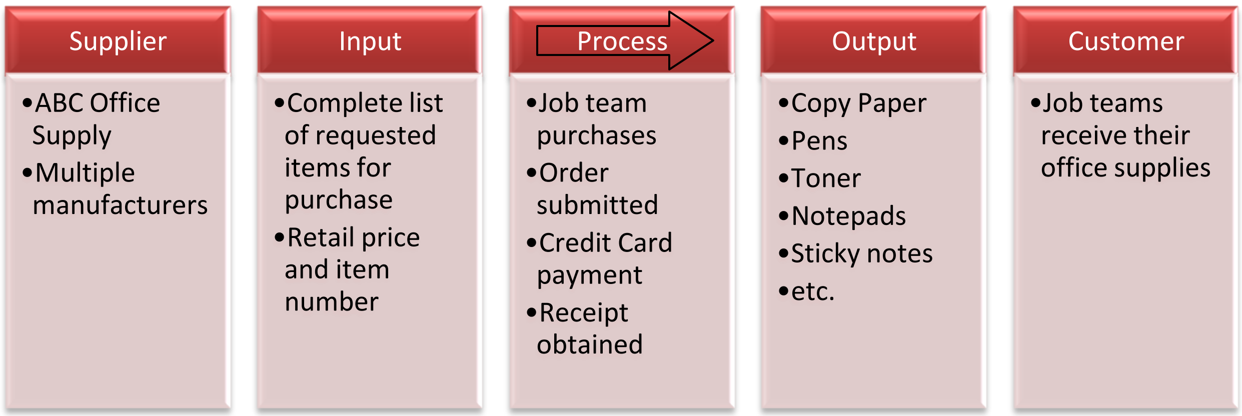

Figure 10. SIPOC diagram for office supply purchases.

Measure phase.

The activities of the Measure phase are:

1. Confirm Team Goal
2. Define Current State (Baseline)
3. Collect and Display Data

SSPI Toolkit.

Recall, that SSPI tools are software programs can be used to implement, manage, and monitor projects. This tool is also seen in the Design Phase. Under the Measure Phase the following example could apply to LEED-EB.

Example:

One of the activities required for a LEED-EB project which can be implemented under the Measure phase is to understand the baseline data. For example, under the EA credits, a baseline energy usage must be determined prior to being able to plan for improvements. The SSPI tool that could be used at this stage is the Energy Star online program (www.energystar.gov). The Energy Star program enables users to calculate the baseline Energy Star score. Appendix 2 (Energy Star 3-24-09 report) shows an example of a report prepared for a LEED-EB project using Energy Star.

Another SSPI tool that could be used for EA is the energy modeling program eQuest. Developed by the Department of Energy (DOE), eQuest is a modeling program that can be used to gain an understanding of where your highest energy consumption exists in the facility. The eQuest Program is used to model energy use of buildings. It is free to download off the internet. Users enter data regarding building design or existing building features. The program models energy load profiles, peak energy and annual energy information including anticipated costs (Figure 11).

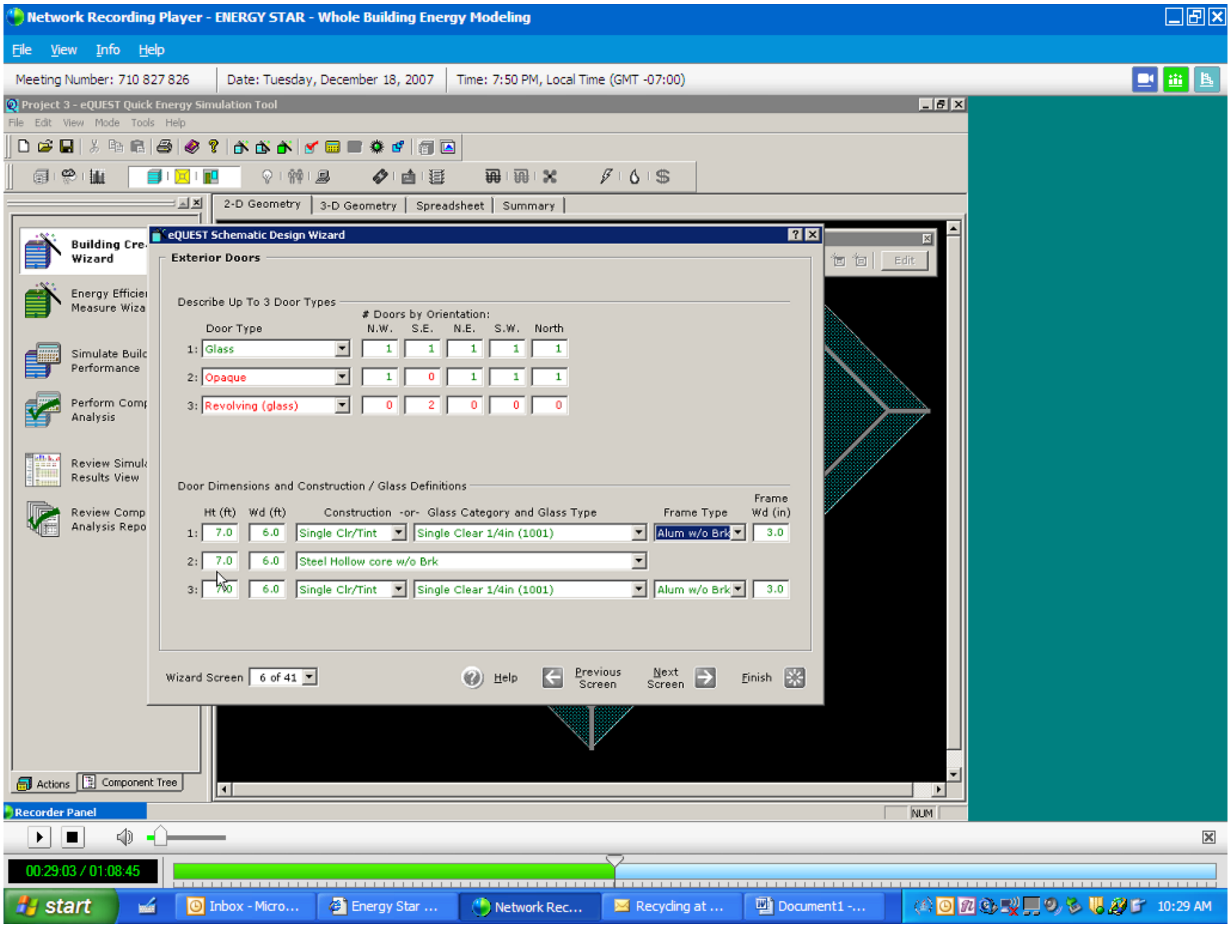

Figure 11. eQuest modeling program.

Using the building construction data and electricity usage information gathered from the LEED-EB project that failed to move past the evaluation, Figure 12 illustrates a report using eQuest.

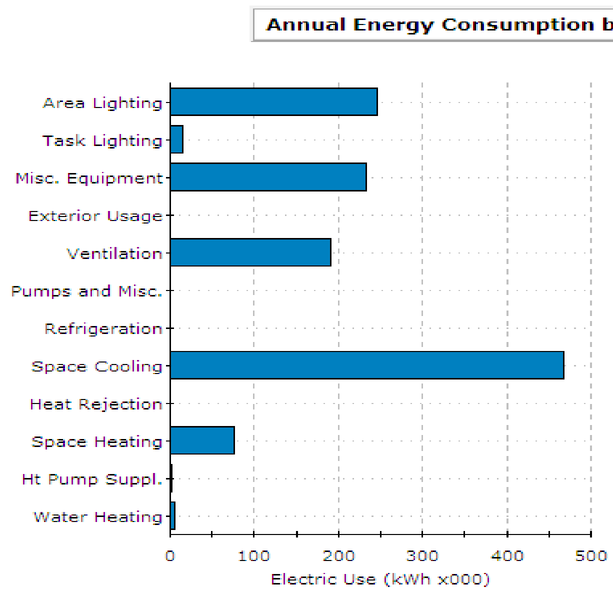

Figure 12. Baseline eQuest energy model of a LEED-EB project.

Process Mapping.

One tool that Six Sigma uses is process maps. Six Sigma Black Belts will tell you that you cannot solve a problem or work on a project until you understand the process.

Example:

Process mapping applies to two areas in a LEED-EB program. First, process maps can help the project team understand what steps they need to take in the process of moving through the LEED-EB program itself. Second, process maps can help the team improve processes within the organization to meet LEED-EB standards.

A process map for the Measure Phase of LEED-EB has been developed for each category (SS, WE, EA, IEQ, MR, RP, and IO). If LEED-EB implementation is the process, then it reasons that an understanding of all that is required to implement LEED-EB should be mapped out from the start. See Figures 3 through 17 for the process maps required to perform the Measure Phase for each of these categories. Within each of the process maps, there are numbered steps. They are numbered and correspond to a step by step procedure to guide the team through the requirements of the LEED-EB certification program. Each of those steps is included in Tables 15 through 19. Some of the steps require checklists and calculations. Examples of the calculations spreadsheets are available in Appendix 3.

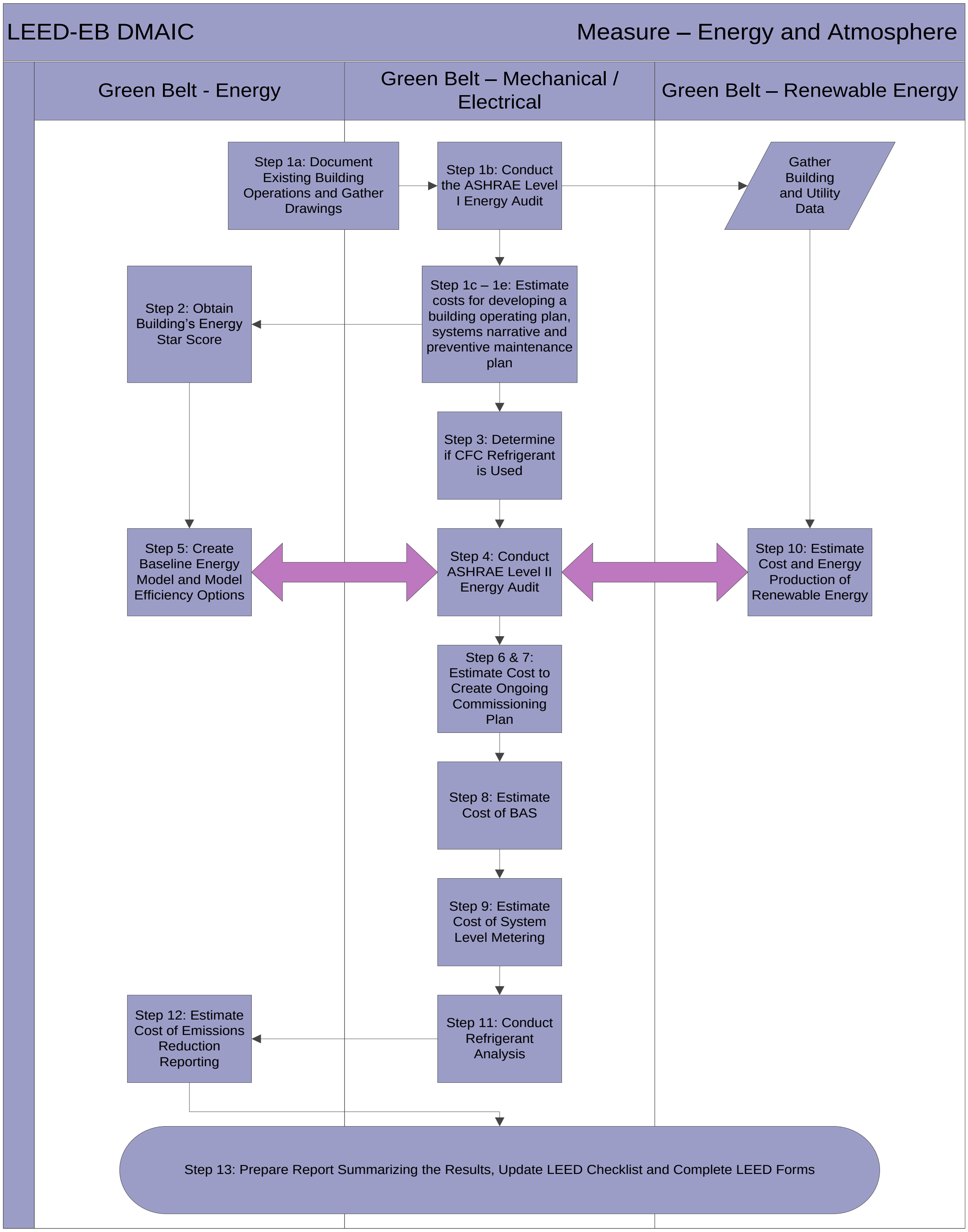

Figure 13. EA process map

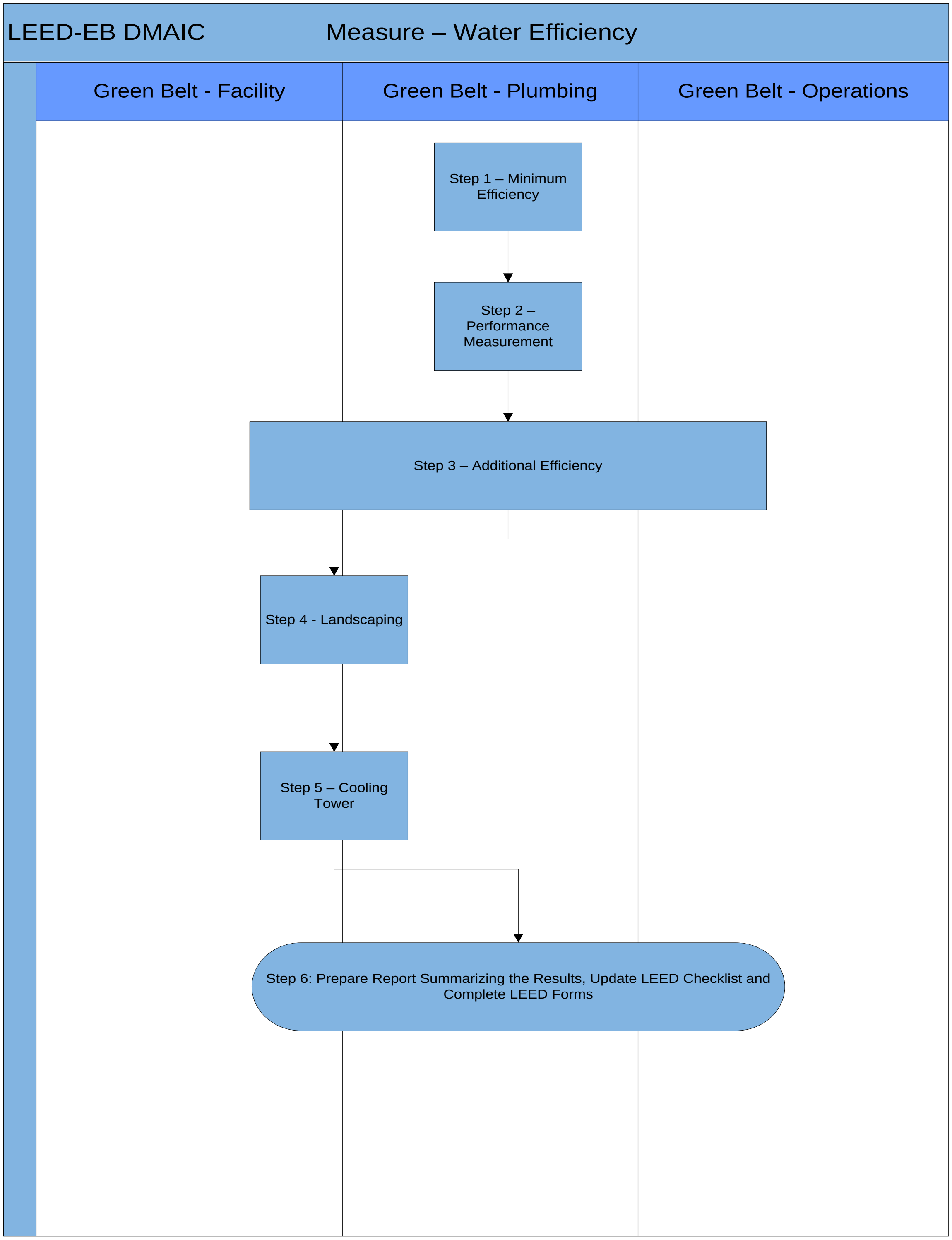

Figure 14. WE process map

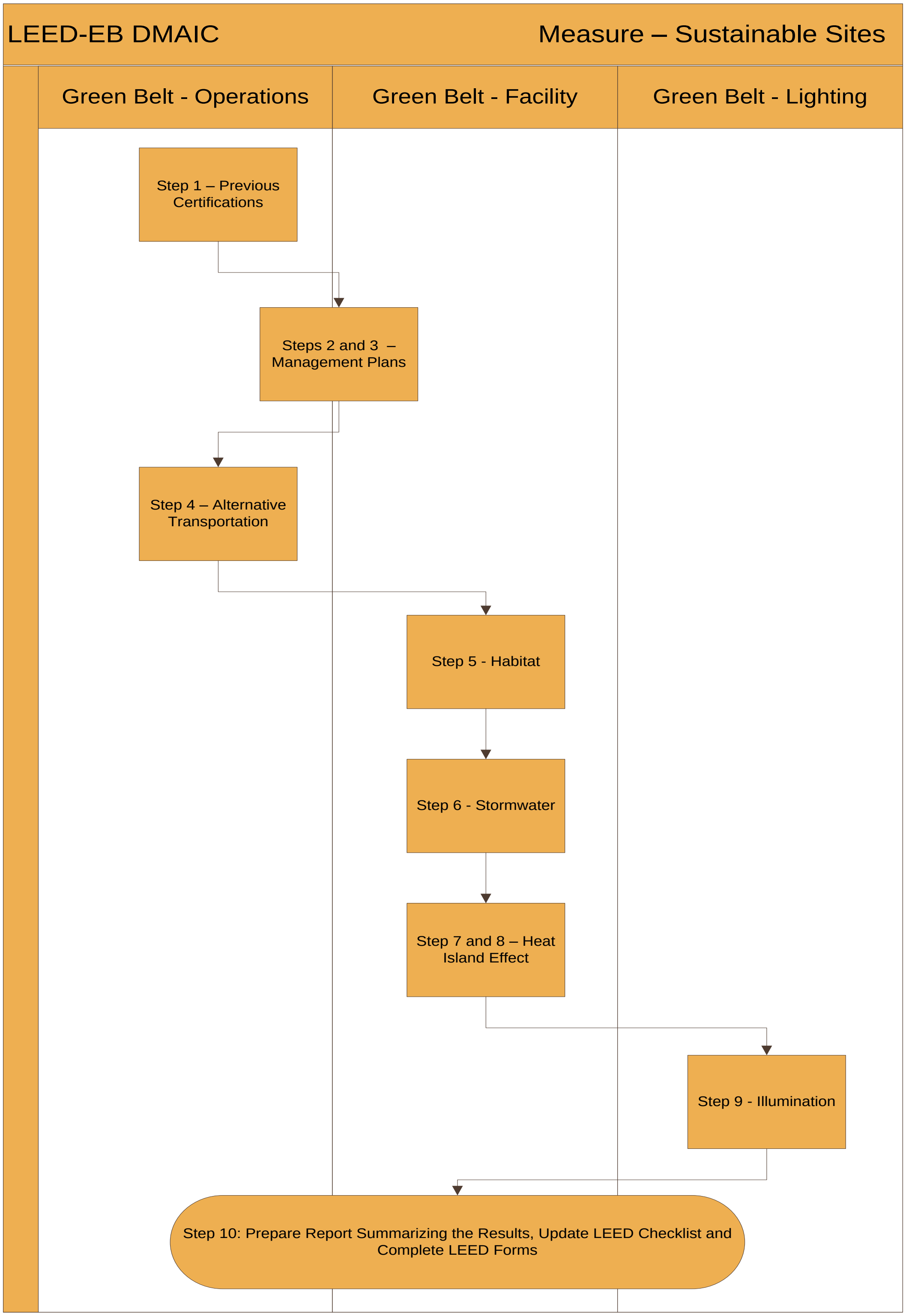

Figure 15. SS process map

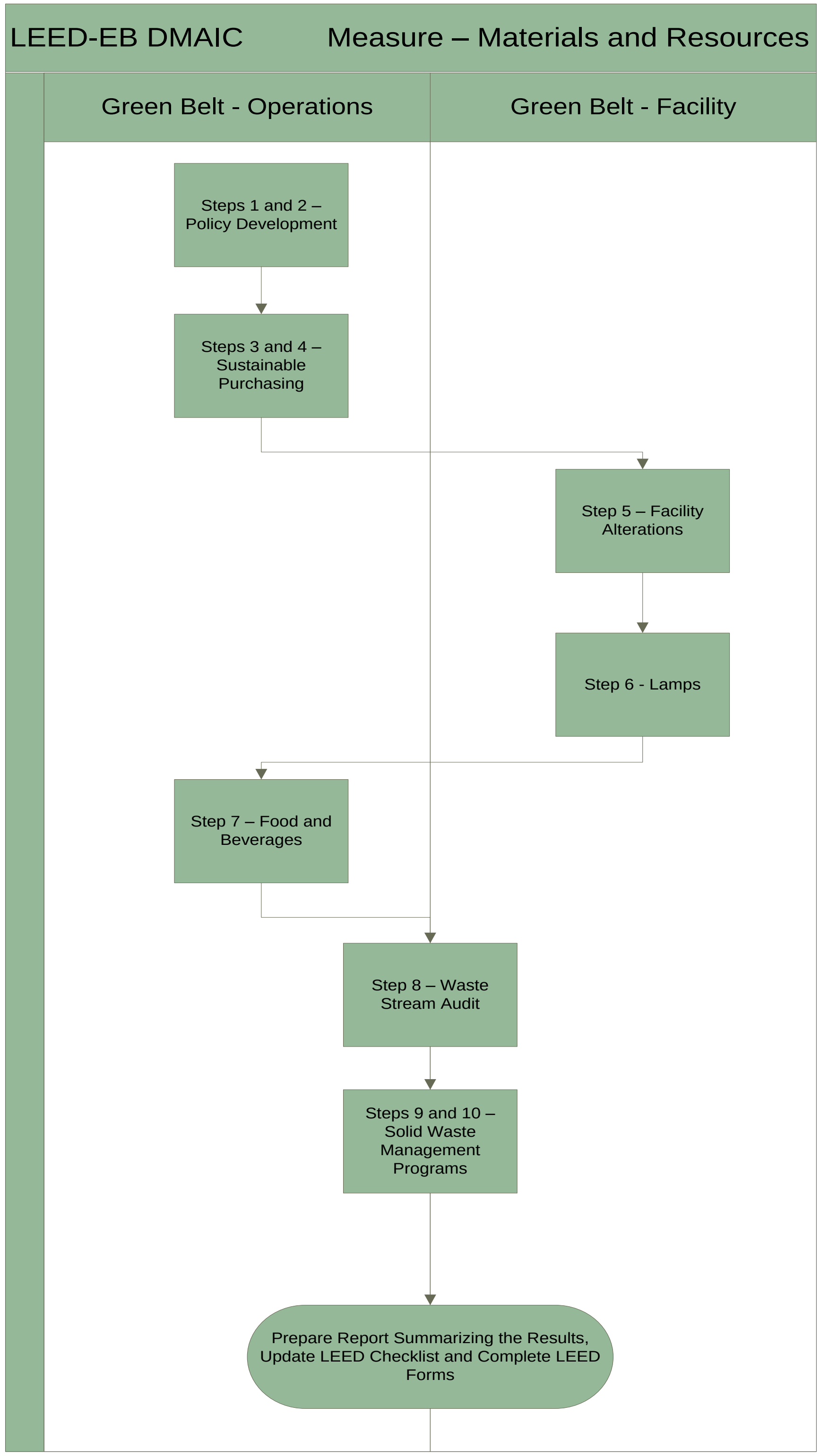

Figure 16. MR process map

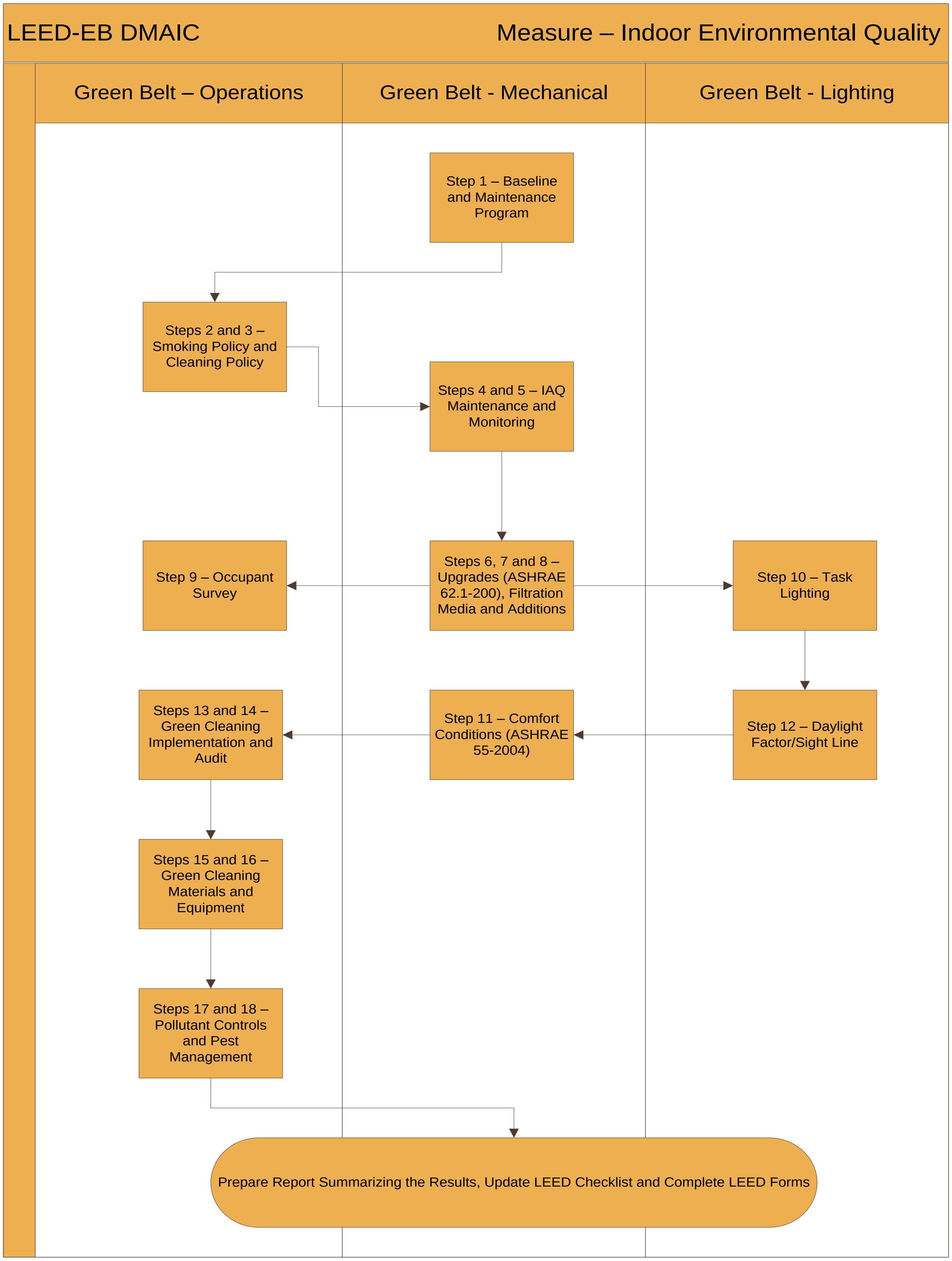

Figure 17. IEQ process map

Table 15.

Step by Step Process for the EA Requirements.

Energy and Atmosphere	
Step 1a	Collect and document existing building operations and plans. This includes maintenance plans and as-builts (EA p1).
Step 1b	Conduct the energy audit, complete forms and prepare report (AHRAE Level 1). Perform the ASHRAE Level 1, walk through analysis. Use the Level One Forms and Calculations. Follow the LEED Report Guidelines.
Step 1c	Estimate costs for developing the building operating plan. See USGBC Reference Guide (Pages 129-130).
Step 1d	Estimate costs for preparing a systems narrative. Explanation of Systems Narrative: Page 131-132 of USGBC Reference Guide.
Step 1e	Estimate costs for preparing the preventive maintenance plan.
Step 1d	Explanation of Preventive Maintenance Plan. See Page 132-133 of USGBC Reference Guide.
Step 2	Obtain the building's Energy Star score using Portfolio Manager (EA p2). Use checklist: Energy Star information request spreadsheet.
Step 3	Determine if CFC refrigerant is used in systems (if <0.5 lbs you are exempt) (EA p3). If Yes, determine cost to convert to zero CFC. Or, Calculate the cost to perform economic analysis and calculate leakage rate (this may exclude you from being required to perform the conversion to zero CFC refrigerant). See explanation of CFC calculation: page 145-148 of USGBC Reference Guide. If No, the project earns the point.
Step 4	Conduct a Level II Energy Audit (EAc2.1). Develop the baseline model using eQuest. Model efficiency performance measures. Locate funding options and incentives (rebates, grants, etc.). <u>See:</u> Level II forms: Pages 34-44 of Commercial Building Energy Audits and 2007 ASHRAE Handbook and Report Guidelines: Pages 7-9 of Commercial Building Energy Audits
Step 5	Target energy efficiency performance measures for the existing facility. (EAc1) Model efficiency performance measures (from equipment to operational changes) using eQuest and estimate effect on Energy Star Score by calculating % reduction.
Step 6	Estimate costs to track costs/benefits throughout the performance period and set up with ongoing maintenance EMS for the implementation of energy efficiency improvements. Estimate cost to provide training to facilities staff. (EAc2.2)
Step 7	Estimate the <u>cost to create</u> an ongoing commissioning plan. (EAc2.3) Plan shall include: Commissioning activity, Commissioning team, Responsible party, Systems, Cycle and schedule, Monitoring, testing and performance verification, Calibrations, Issue identification and response report.
Step 8	Is there an existing building automation system (BAS) in the facility? (EAc3.1) If Yes- Is it being used and how much to update it (if required)? If No- What is the cost to install new? Is tit feasible to pursue this credit?
Step 9	Is there system level metering at 40% or 80% of the total expected annual energy consumption (by cost) of the building? (EAc3.2)

	If Yes- Is it being used, how much to update it to LEED-EB requirements (if necessary)? If No- Is this project a candidate for system level metering? If it is… what is the cost to install per LEED-EB Requirements?
Step 10	Are there existing renewable energy systems being used for the facility either on-site or off-site? (EAc4) If Yes- How much electricity does it supply and what % of building's total energy use will it provide? If No- How much would it cost to install / at what level of energy?
Step 11	What refrigerants (and quantity) are used in the existing facility and do they meet the LEED-EB requirements? (EAc5) If the facility qualifies – earns the point If the current facility does not qualify - calculate the cost to upgrade Attachments: Explanation and Calculations for EAc5: Pages 215-223 of USGBC Ref Guide
Step 12	Calculate the cost to perform emissions reductions reporting and report to the EPA. (EAc6)

Table 16.

Step by Step Process for the WE Requirements.

	Water Efficiency
Step 1	What is the fixture and fitting performance of the existing facility? (WEp1). See attached calculations form. Complete digital form. Develop and implement a policy requiring economic assessment of conversion to high performance plumbing fixtures and fittings. Conduct economic assessment to convert existing plumbing to high-performance plumbing. Assessment must include potential water supply and disposal costs savings and maintenance cost savings.
Step 2	Does the building have a permanently installed water meter? (WEc1) If Yes – Project has earned the point. If No- What is the cost to design, install and maintain? Does the building have sub-metering? See calculations form (pages 95 – 96 in USGBC reference guide). If Yes – Project has earned a second point. If No- What is the cost to design, install and maintain?
Step 3	What measures can be taken to reduce the calculated baseline water use by 10%? (WEc2). What is the cost to design, install and maintain these measures?
Step 4	What is the baseline irrigation use of the existing facility? (WEc3). See attachment for calculations sheet. Complete excel spreadsheet saved in shared drive. What is the target % reduction for this facility? What is the cost to design, install and maintain?
Step 5	Does the facility have a cooling tower? (WEc4) If Yes- What chemicals are used? Is water used?

Table 17.

Step by Step Process for the SS Requirements.

Sustainable Sites	
Step 1	Was this building previously certified by USGBC? (SSc1) If Yes – earn point, complete SS Credit 1 form and submit to LEED online. If No – no point earned, do not seek credit
Step 2	Is there an existing Building Exterior Hardscape Management Plan? (SSc2) If Yes - Does it meet the requirements of LEED? See attachment for explanation (USGBC Reference Guide Page 9) If No – Estimate the cost to create, implement and sustain the plan.
Step 3	Is there an existing Pest Management Erosion Control and Landscape Management plan? (SSc3) If Yes - Does it meet the requirements of LEED? See attachment for explanation (USGBC Reference Guide Page 15) If No – Estimate the cost to create, implement and sustain the plan.
Step 4	What is the current level of Alternative Transportation? (SSc4) What is the baseline level? The baseline level assumes all regular occupants commute alone in conventional automobiles. See attachment for explanation on calculating baseline case (USGBC Reference Guide page 23). Does the facility participate in a local or regional commute reduction program? If Yes – What level of occupants are commuting based on the survey? If No – Perform a survey. See attachment for explanation (USGBC Reference Guide page 26-30). Based on the results of the survey: -How many points does the current level earn? -How many points are we targeting? -What changes can be made to increase the level of alternative transportation? -What is the cost of creating and implementing a new program to get the level of -points we need?
Step 5	Determine the area of on-site natural area, off-site natural area or vegetated roof area that meet the definition of native or adapted vegetation, water bodies, exposed rock, and bare ground. (SSc5) See attachment for calculation sheet and complete form. What measures can be taken to increase the amount of habitat? What is the estimated cost to increase the % of habitat?
Step 6	Is there an existing stormwater management plan? (SSc6) If Yes - Is at least 15% of the runoff collected or reused onsite? Does the collection system have the correct drawdown level? See

	attachment for calculation sheet and complete form. If No – Estimate the cost to: Create, implement and sustain a plan that meets the requirements of LEED-EB. Install and maintain pervious pavement, rainwater harvest cistern, etc.
Step 7	What percentage of the hardscape is currently covered by shade, SRI 29 paving materials, open grid system or covered parking with SRI of 29? Does it cover at least 50% of the hardscape? (SSc7.1) See attachments for calculations and complete forms. If Yes – You have earned the credit. If No – What is the cost to design, construct and maintain to meet 50% requirement?
Step 8	What percentage of the existing roof has an SRI of 78 for a low-sloped roof ($\leq$ 2:12) or an SRI of 29 for a steep-sloped roof (>2:12) or is vegetated? (SSc7.2) See attachment for calculations. Complete the form. Does it meet the LEED requirements? If Yes – Credit earned If No - What is the cost to design, construct and maintain new roof?
Step 9	Answer the following questions: 1. Is indoor lighting automatically controlled to turn off during all after-hours periods at a rate of 2,190 hours per year? AND 2. Do existing exterior fixtures which are 50 watts and over have partially or fully shielded covers to cast light downward? OR #1 AND #3 3. What are the night illumination levels? (SSc8) NEED to either purchase a light meter or hire a third party to do option 3 of this analysis. See attachment (pages 71-72 of the USGBC Reference Guide) for further instructions. Are the requirements already met at this facility? Must meet either options 1 and 2 or options 1 and 3. If Yes – Earned the credit. If No - What is the cost to design, install and maintain new lighting?

Table 18.

Step by Step Process for the MR Requirements.

Materials and Resources	
Step 1	Is there an existing purchasing policy for the facility? (MRp1) If Yes – Does it meet the requirements of LEED? If No- What is the cost to update it? If No (do not have one) – What is the cost to write one?
Step 2	Does the facility have an existing solid waste management policy? (MRp2) If Yes – Does it meet the requirements of LEED? If No- What is the cost to update it? If No (do not have one) – What is the cost to write one?
Step 3	What is the baseline/current % of sustainable purchases for ongoing consumables (by cost)? (MRc1) Complete spreadsheet calculations.Estimate the cost to increase to LEED standards.
Step 4	What is the baseline/current % of sustainable purchases for durable goods (by cost)? (MRc2)Estimate the cost to increase to LEED standards.
Step 5	Will there be facility alterations and additions during the performance period? (MRc3) If Yes – Estimate the cost for LEED requirement.
Step 6	Calculate the quantity, type and location of lamps that contain mercury in the existing facility. (MR4) Calculate the average pictogram per lumen. – add calcs Identify replacement options and costs. Estimate cost to develop purchasing plan.
Step 7	Are food and beverages purchased for the facility (either in a café or deli, etc)? (MRc5)What % of the food and beverage purchases is sustainable? What is the cost to increase to LEED requirements?
Step 8	Perform the baseline audit of the waste stream of the existing facility (MRc6)
Step 9	After the audit is performed determine what the cost of reusing, recycling or composting 50% of ongoing consumables. (MRc7)
Step 10	After the audit is performed determine what the cost of reusing, recycling or composting durable goods. (MRc8)

Table 19.

Step by Step Process for the IEQ Requirements.

Indoor Environmental Quality	
Step 1	Perform indoor air quality calculations (IEQp1): 1. Calculate the baseline indoor air quality of the facility using ASHRAE 62.1-2007 Case 1 calculation (see excel spreadsheet called "Ventilation Rate Procedure" in file). 2. Determine if the levels meet ASHRAE 62.1-2007. If they do not qualify, move to Case 2 for 10cfm of outdoor air per person requirement. See excel spreadsheet called "xxxx". If Yes – No changes required If No – Determine what changes need to be made and estimate the cost of those changes. 3. Is there an HVAC system maintenance program? If Yes – Does is meet LEED requirements? If Yes – No changes If No- go to next to do item 4. Estimate cost to develop and implement HVAC system maintenance program. Estimate cost to test and maintain exhaust system.
Step 2	What is the current smoking policy of the facility? Does it meet LEED requirements? (IEQp2) If Yes – no changes required. If No – What is the cost to develop and implement a new policy?
Step 3	Who is the current cleaning company and is there an existing cleaning policy? (IEQp3) If there is an existing policy, does it meet the LEED requirements? If Yes - No changes If No – What is the cost to develop and implement a cleaning policy? And what are the long term costs of this policy?
Step 4	Is there an existing IAQ management program? Does it meet the requirements of EPA's I-BEAM? Tasks include: conducting an indoor air quality (IAQ) building audit; diagnosing and resolving IAQ related health problems; establishing an IAQ management and maintenance program to reduce IAQ risks; planning IAQ compatible energy projects; protecting occupants from exposures to construction/renovation contaminants; and calculating the cost, revenue, and productivity impacts of planned IAQ activities. (IEQc1.1) If Yes – No changes If No – What is the cost to develop and implement a cleaning policy? And what are the long term costs of this policy?
Step 5	Does the facility have an existing monitoring system that provides feedback on ventilation system performance including CO_2 sensors? (IEQc1.2)

	If Yes – Does it meet LEED requirements? (See pages 361-369 of USGBC ref guide) attachment XXX If No – What would a new/upgraded system cost?
Step 6	Determine what a 30% increase above ASHRAE 62.1-2007 would be for this facility (IEQc1.3)The same calculations are used to document IEQ p1 as are required for this credit. Estimate the costs of these upgrades.
Step 7	What filtration media is currently used in the facility? (IEQc1.4) What filtration media can be used with the new HVAC units that may be installed as part of the energy efficiency retrofit? Estimate first cost and long term costs of filtration media of MERV 13 or greater.
Step 8	Are there plans for alterations and additions during the performance period? (IEQc1.5) If Yes – What are the costs for develop and implement an IAQ plan for this phase.
Step 9	What is the cost to develop and conduct an occupant survey during the performance period and for future delivery? (IEQc2.1)
Step 10	What is the level of task lighting in the existing facility and are there control capabilities? (IEQc2.2) What is the cost to implement and install new lighting?
Step 11	Does the facility have existing systems that will monitor and track indoor comfort conditions such as humidity, temperature and air speed, etc? (IEQc2.3) If Yes – does the system meet the LEED and ASHRAE 55-2004? If No – Estimate the cost to implement and install.
Step 12	What are the daylight factor levels of the current facility? What are the direct line of sight levels? - NEED MORE INFO HERE (IEQc2.4) Does it meet the LEED requirements? If Yes – No change If No – What options are there to meet LEED requirements? And how much will those options cost?
Step 13	Is there a green cleaning program currently being implemented at the existing facility? (IEQc3.1) If Yes – Does it meet the LEED requirements? If No – How much will it cost to develop and implement a new cleaning program?
Step 14	Estimate the cost for developing and conducting a green cleaning audit. (IEQ3.2) Perform audit during performance period but when?
Step 15	Determine what materials and products are used for cleaning the facility. (IEQ3.3) Do these materials meet the LEED requirements (30% of purchases are sustainable products)? If Yes – Earn the credit If No – How much will it cost to upgrade purchases?
Step 16	Determine what equipment is used for cleaning the facility. (IEQ3.4) Does this equipment meet the LEED requirements (green label

	vacuum cleaners, etc)? If Yes – Earn the credit If No – How much will it cost to upgrade?
Step 17	What chemical and pollutant source controls are currently in place at the facility? (IEQc3.5)Does it meet LEED requirements? If Yes – Earn the credit If No – What will it cost to install new controls?
Step 18	Does the facility have an existing green cleaning /indoor pest management plan? Does it meet LEED requirements? If Yes – Earn the credit If No – What will it cost to develop, implement and maintain the policy?

Additional process maps could be prepared for the other phases of LEED-EB as well as for the projects that LEED-EB will implement. Notice that each of the steps also shows the responsible person on the process map. The step by step detail shows the information that will be required.

Brainstorming.

The Brainstorming Tool is an area for open collaboration of ideas. All ideas are written down and then through a process of elimination or other method, the outcomes are determined and selected.

Example:

During the Measure Phase of a LEED-EB project the Green Belts and Black Belts could hold a brainstorming session to determine which categories for LEED-EB to focus on based on knowledge that everyone already has of the facility. Green Belts are those team members that are familiar with the facility and with the operations.

Pareto Charts.

Pareto Charts are essentially bar charts that have one additional feature, a cumulative effect bar. Pareto charts can be used to identify the impact of one variable and cumulative effect of all the variables. The charts allow the team members to determine which variables have the greatest impact on process or the outcome.

Example:

In LEED-EB, Pareto Charts can be used to identify the variables that have the greatest impact on preventing the company from reaching its sustainability goals. Pareto charts could be used for instance to find waste in a process whether it be material, water or energy waste. One example is to utilize the eQuest data obtained from the model regarding energy usage, and add the Pareto cumulative % bar to a column chart (Figure 18).

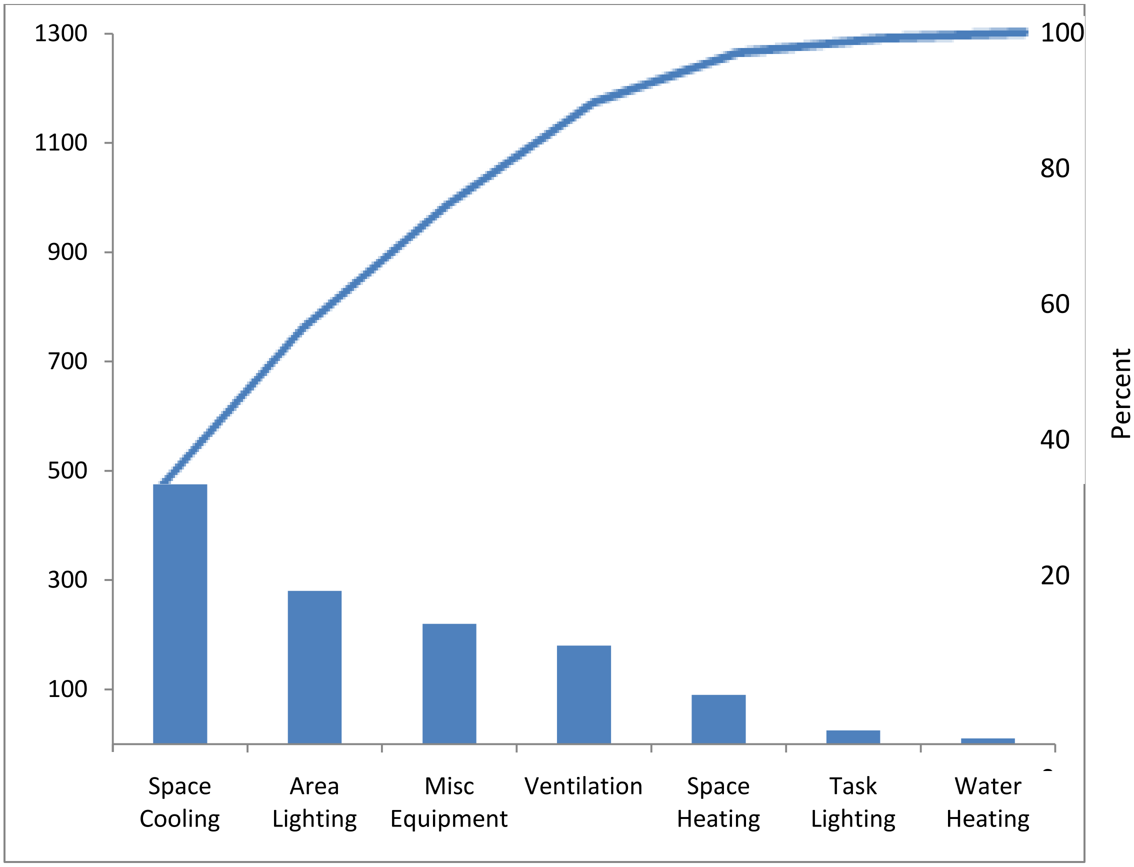

Figure 18. Pareto Chart showing energy consumption.

Cause-and-Effect Matrix (C&E).

The C&E Matrix tool is used to identify process input variables and evaluate the strength of their relationship to the outputs. This is beneficial to the Six Sigma team in helping them to quickly eliminated less important steps in a process that do not impact the outputs. This is extremely useful when no data exists.

Example:

In a LEED-EB project, the C&E Matrix could be used to examine the benefits of various projects to weight them and prioritize them for project selection purposes. For instance, if there are several options for obtaining LEED points, but there is a limited budget and upper management has stated that they want to implement the projects that have the most value, return on investment is not always the most important parameter to consider. Other benefits of a project might be long term savings, pollution prevention, resource conservation, employee morale, marketing promoter, etc. Each of the benefits is weighted on level of importance to the goals of the company (as determined during the Define Phase or during Part 1 of the LEED-EB program). If we develop a C&E Matrix, we can put some values to these outputs. The team determines the scale. These are subjective, but better than nothing.

The team then scales the processes, or projects in this case. One example of a scale to select would be as follows:

0=None 1=Low 3=Moderate 9=Strong

The team might select this scale, because it allows the strong scores to really stand out above the rest, which is what you are trying to do, find the strongest projects or the strongest variables. For our example on the LEED-EB project, we might have a list of projects such as:

Green purchasing program, retrofit lighting, retrofit plumbing fixtures, native landscaping, and increase natural day-lighting. A table is then developed as is shown in Table 20.

Table 20.

C&E Matrix for Six LEED-EB Project Opportunities.

	Long Term Savings	Pollution Prevention	Resource Conservation	Employee Morale	Marketing Promoter	<<Output Indicators
	10	9	8	6	4	<<Importance
Input/Output Indicators	Correlation of Input/Process to Output Indicators					TOTAL
Green purchasing program	0	3	9	3	3	129
Retrofit light fixtures	3	3	9	1	3	147
Retrofit plumbing fixtures	1	0	9	1	3	100
Native landscaping	1	0	9	3	9	136
Increase natural day-lighting	1	3	3	9	3	127
	Correlation Scale: 0=None 1=Low 3=Moderate 9=Strong					

Based on the results of the C&E Matrix, the most important project to pursue would be retrofitting the lighting, which came in at a score of 147. The second most important project would be to plant native landscaping. It earned a score of 136. A green purchasing program came in third. Increasing natural day-lighting came in fourth. Retrofitting plumbing fixtures came in fifth.

The calculation used to arrive at the total is as follows:

$$\text{Total} = \text{Sum (Input/Output Indicator} \times \text{Importance Score)} \qquad (4)$$

For instance, the Green Purchasing Input had the following results:

Long term Savings = 0 x 10 = 0

Pollution Prevention = 3 x 9 = 27

Resource Conservation = 9 x 8 = 72

Employee Morale = 3 x 6 = 18

Marketing Promoter = 3 x 4 = 12

Total Importance (Sum of the above) = 129

Fishbone Diagrams.

A Fishbone Diagram is also a Cause and Effect tool. It is an idea generating or brainstorming tool, used to illustrate potential causes that require further investigation. These diagrams do not represent actual data, but rather potential causes and effects that require more research. A Fishbone Diagram may include a few or all of these six categories: Measurements, Materials, Machines, Manpower, Methods and Mother Nature (George, 2002, p. 193).

Example:

A fishbone diagram could be use on a LEED-EB project to pinpoint potential causes of waste in a process. If we use the example of recycling during renovations, we can create a fishbone diagram to illustrate all of the components of a construction recycling program (Figure 19). The team could then use this diagram to investigate any areas that may require additional research and data collection.

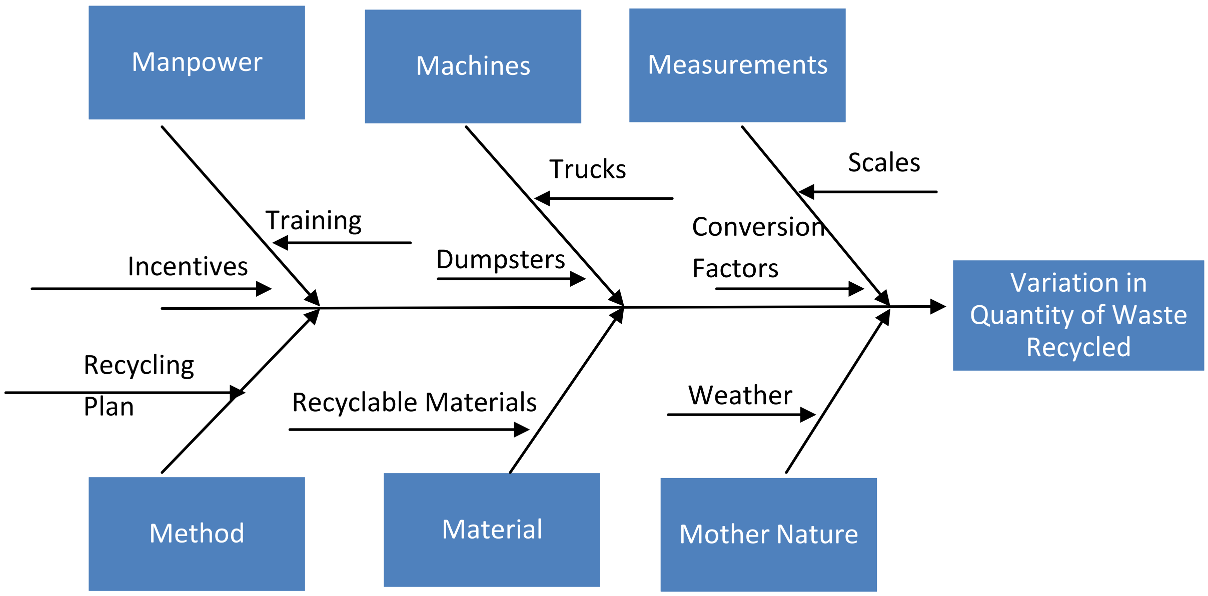

Figure 19. Fishbone diagram of a LEED-EB construction waste recycling project.

Check Sheets.

The majority of the information gathered for a project is performed during the Measure Phase of DMAIC. Teams have benefitted from using Check Sheets to ensure that all of the required data is collected during this phase. A Check Sheet is a table or a list of items with check boxes that can be filled out by the team members or by those the team is requesting information from.

Example:

Check Sheets are very important to a LEED-EB project. Each and every credit targeted and earned will require extensive data and documentation. Check Sheets help to organize information in one place for easy data entry into programs such as Energy Star (Appendix 4) or modeling programs such as eQuest (Appendix 5). LEED-EB requires that teams utilize some checklists such as the ASHRAE Level 1 and Level 2 forms that are already prepared and ready for use.

Run Charts.

A Run Chart is used to graphically display how data changes over time. This enables teams to decipher patterns in the data.

Example:

A Run Chart could be used on a LEED-EB project to understand material usage over time, CO_2 levels in the building, energy consumption or a variety of other time based data. For instance, if a LEED-EB project created a Run Chart for Energy Consumption, they could analyze how energy is used throughout the day, or even throughout the year. This would help them in the future phases of DMAIC to plan for improvements and ultimately reduce energy consumption.

For the energy consumption example, the team could collect previous utility bills and graph the results over several months to several years. A Run Chart is provided in Figure 20.

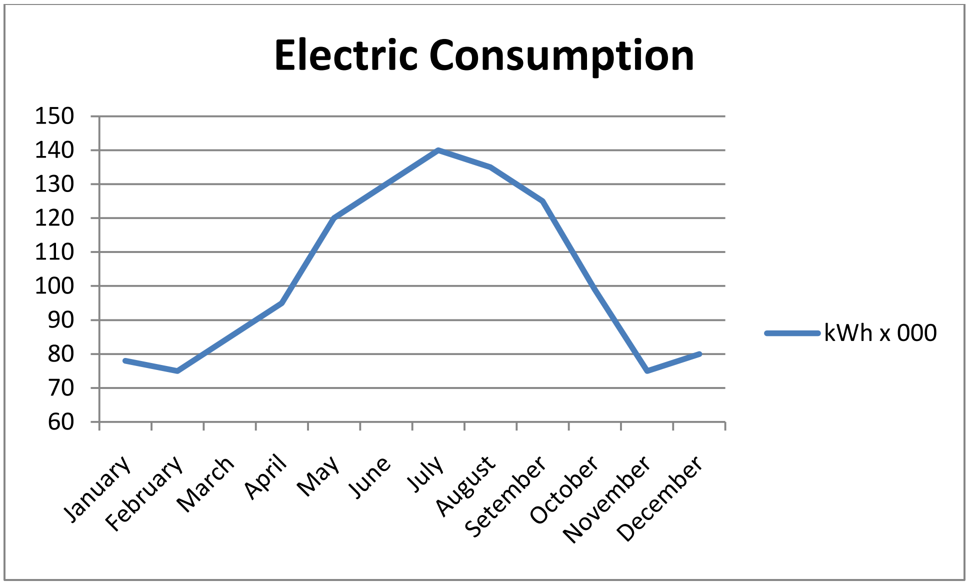

Figure 20. Electric consumption run chart.

Control Charts.

Control Charts are essentially Run Charts with the addition of detailed statistical analysis. Control Charts follow the basic structure of including data points plotted in time order (as we saw in the Run Chart), and a centerline representing the average and control limits which indicate the expected amount of variation. There is also an upper control limit (UCL) and a lower control limit (LCL).

Example:

If we use the Run Chart prepared previously and add the additional statistical tools, we can create a Control Chart (Figure 21). The Control Chart is then used to view areas where variation is occurring that we may not expect. For instance, the Control Chart in Figure 21, depicts electric consumption that follows the weather patterns of the region (hot in the summer and mild winters). It is likely that the majority of the electricity used in the summer months is for space cooling. If the Control Chart appeared as the example in Figure 22, we might want to investigate what the unexpected cause of that spike is. Perhaps the spike was caused by something that could be controlled or needs to be fixed. A Control Chart would then help the team in finding the problems and then finding the solutions.

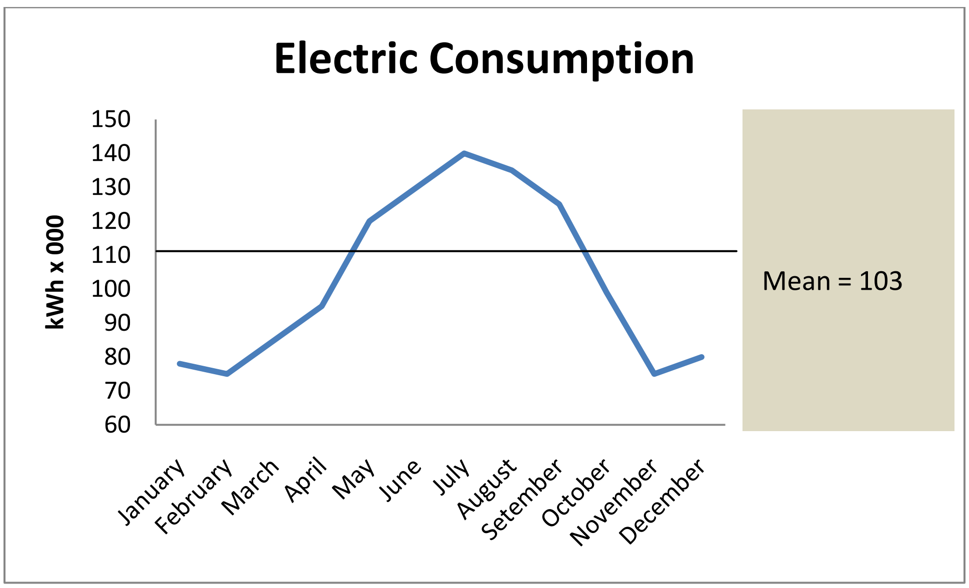

Figure 21. Control chart showing energy consumption.

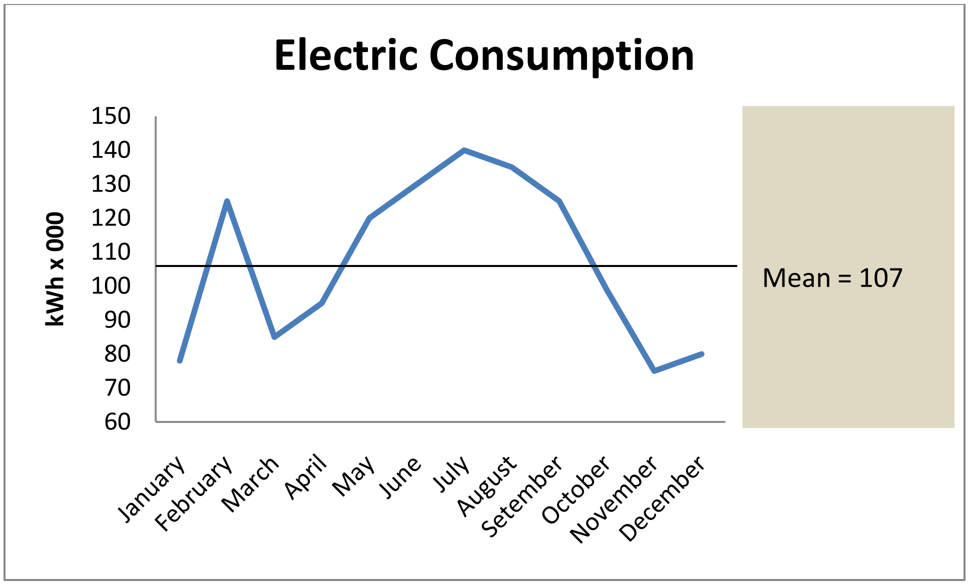

Figure 22. Control chart showing a spike in energy consumption.

Gage Repeatability and Reproducibility (R&R).

The Gage R&R is essentially a data control tool. It ensures quality in the data that the team is going to use to make in many cases very big decisions. Data collection needs to be both "repeatable" meaning that a person taking a reading of the same item using the same instrument will get the same answer. "Reproducibility" means that different people will be able to get the same answer on the same item using the same instrument. Gage R&R measures variability in the data collected over several runs. The Green Belt could ask three operators to measure ten parts, three times each. The data is then analyzed for variability. If the measurement variation is above 30%, the process needs to be improved before it should be considered reliable data. The goal of Gage R&R is to increase the confidence in the data (George, 2002, pp.194-195).

Example:

Gage R&R is applicable to LEED-EB programs that are implemented in industrial settings which are collecting data on equipment used to in the process. It could also be used for LEED-EB programs in office settings. Gage R&R is particularly applicable to the Implementation and Control Phases of a LEED-EB Program. One example of how it might be utilized involves the ongoing commissioning credit (EA Credit 2.3). During implementation of the commissioning, it would be important to ensure that the written plan provides a set procedure to ensure that the ongoing commissioning is repeatable and reproducible. The same can be said of all of the other plans that are prepared for LEED-EB. They must be clear enough that they can be repeatable and reproducible.

Analyze phase.

Activities:

1. Determine Capability for LEED-EB Credits
2. Determine Sources of Variation and Time Bottlenecks

Scatter Plots.

Scatter Plots help teams determine if there is a correlation between two sets of data. Scatter Plots enable researchers to determine which factors impact a process.

Example:

A Green Belt can utilize Scatter Plots to analyze the energy data of a facility. One very simple way to explain how this might work would be to determine if the average outdoor temperature in a given month impacts the monthly utility costs. We already know the answer to this, but it helps to illustrate the example. Figure 23 shows a Scatter Plot of the relationship between outdoor temperature and utility bills. If you can discern a clear trend in the data, you can support a relationship between the two sets of data.

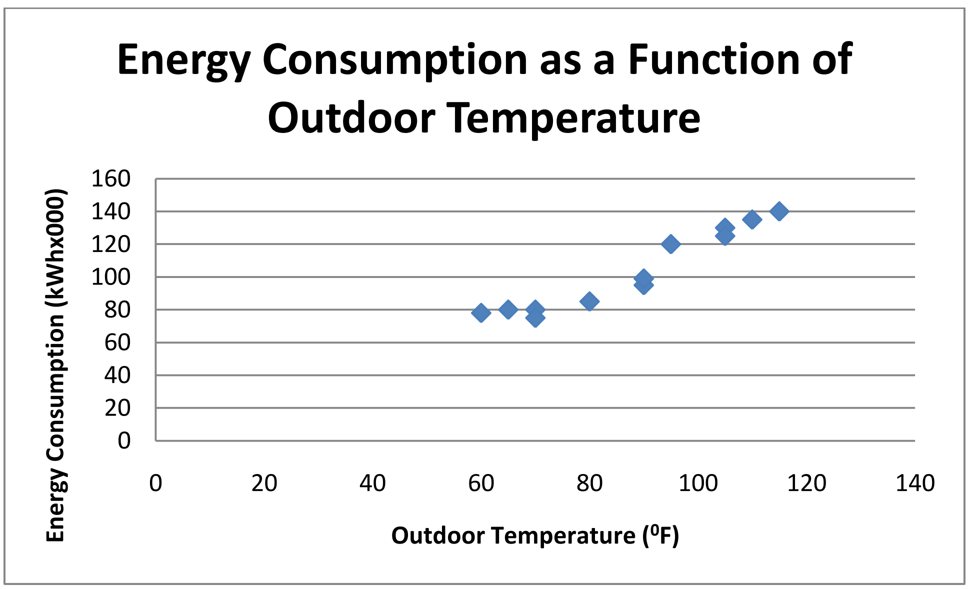

Figure 23. Energy consumption as a function of outdoor temperature scatter plot.

Scatter Plots could be used in other areas of LEED-EB during the analysis phase. Another example of how a Scatter Plot might be used in LEED-EB involves the Fishbone Diagram prepared in Figure 19. From this diagram that we created in the Measure Phase, we see that there are many variables that impact the quantity of materials that are recycled. If a corporation already has an existing recycling program and their goal for LEED-EB is to increase that recycling rate, they need to analyze what variables are preventing higher recycling rates. They might collect data for each of the variables and run a Scatter Plot to see which variables correlate with the quantity of recycled materials. In Figure 24, we see that the percentage of employees trained in recycling has an impact on the recycling rate. The LEED-EB team would likely target training as a program to improve in order to increase recycling rates.

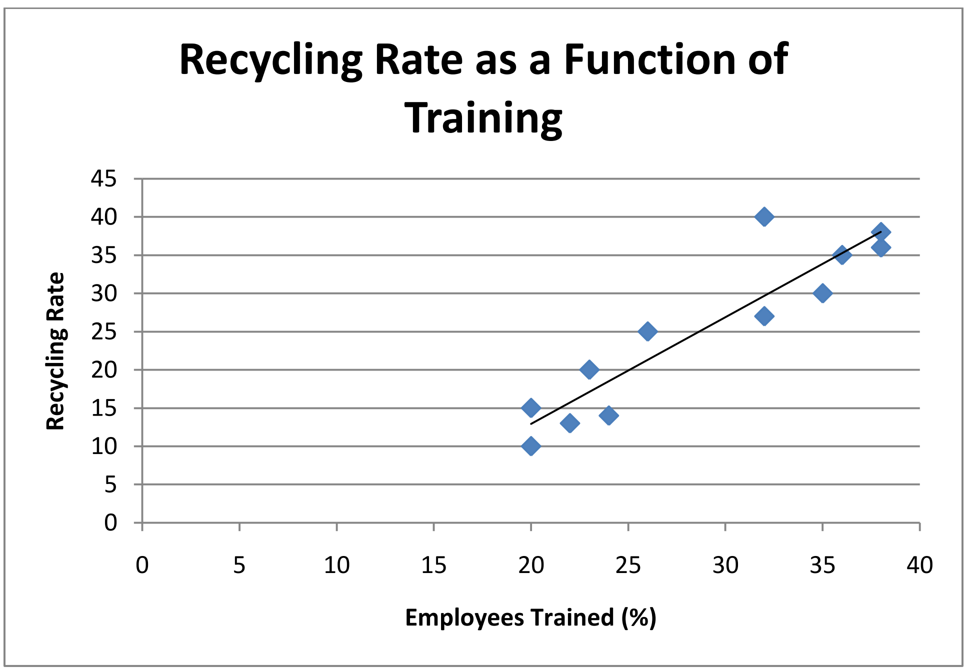

Figure 24. Recycling rate as a function of training scatter plot.

Analysis of Variance (ANOVA).

ANOVA is used to determine if the variance seen in a process is significant and requires standardization in order to reduce the variance. The ANOVA tool helps to identify which factors affect the output (George, 2002, p. 200). Statistical packages such as Minitab are used to run these assessments.

Example:

ANOVA could be used on a LEED-EB program to determine which variables are impacting the current levels of recycling or current levels of energy conservation. Similar to the Scatter Plot diagrams, ANOVA can help team members determine which variables to target for improvements. The team would likely invest in a software application such as Minitab to complete this analysis.

Regression Analysis.

Regression Analysis utilizes the information obtained from the ANOVA, but takes it one step further. By utilizing the Regression Analysis tool, a model is created that quantifies the relationship between the variables.

Example:

Regression Analysis can help a LEED-EB project team by identifying a mathematical formula for predicting future improvements. For instance, if the team performs research and discovers that there is a correlation between sick time and day-lighting, a model could be created to predict what would happen to the areas of the facility where day-lighting could be improved.

To explain this further we can analyze how it might work in a real world example. The situation is as follows:

Area A was construction in 1979 when energy efficient design equated to fewer windows. There are 97 employees working in Area A. Those 97 employees took 495 sick days in the past twelve (12) months. Each employee took on average five (5) sick days in the past twelve (12) months. Area B was recently added on to the facility in 2007. The ratio of window to wall area is about 50% greater than that of Area A. There are 102 employees working in Area B. In the past twelve (12) months employees in Area B took a total of 198 sick days. That is an average of two (2) sick days per employee in one year. Based on this data, the ANOVA would show a significant difference in these two areas and using Regression Analysis, the team could develop a model that would show how much sick time would decrease in Area A, based on various levels of increased day-lighting. The cost of implementing this improvement may be cost prohibitive, but this is an example of how the Regression Analysis might be used in a LEED-EB program.

Improve phase.

Activities:

1. Generate Ideas
2. Conduct Experiments
3. Create Straw Models
4. Conduct B's and C's
5. Perform Cost / Benefit Analysis
6. Develop Action Plans / Select Projects
7. Implement & Construct

Gantt Charts.

Gantt Charts are scheduling tools used by projects managers in many fields and industries.

Example:

A LEED-EB Program can utilize Gantt Charts to stay on schedule. This includes each phase of the DMAIC process as well as the actual implementation of the LEED-EB projects. An example of a Gantt Chart that might be utilized to track progress (Figure 25).

Act ID	Description	Start	Finish	RD
1000	SITE/BUILDING EVALUATION	18-Aug-08	29-Aug-08	10
1005	KICK OFF MEETING - AS BUILTS	02-Sep-08	02-Sep-08	1
1010	SITE BUILDING AUDIT	03-Sep-08	23-Sep-08	15
1015	LEED EB CHECKLIST	24-Sep-08	14-Oct-08	15
1020	PROPOSED SCOPE	15-Oct-08	11-Nov-08	20
1030	BUILIDNG OPERATIONS PLAN	12-Nov-08	11-Dec-08	20
1025	COMPUTER MODEL	12-Dec-08	13-Jan-09	20
1035	OPTIONS/ALTERNATES	14-Jan-09	10-Feb-09	20

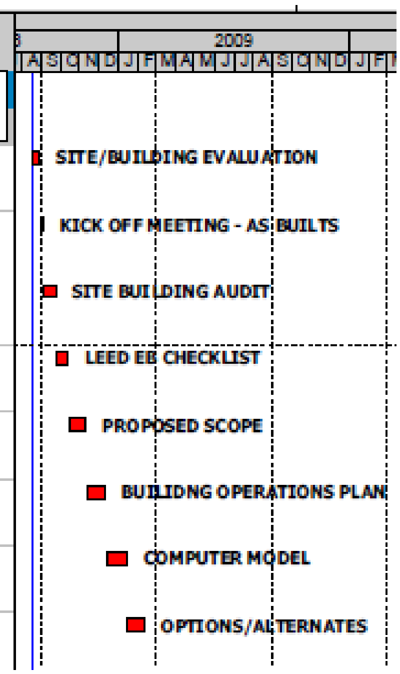

Figure 25. Sample Gannt Chart showing schedule for a few EA requirements.

Mistake Proofing (Poka-Yoke).

Mistake Proofing, known as poka-yoke in Japan, follows the concept that if you kick out a defective part early in the process, it will prevent problems further down the process line. This typically is applied to assembly lines. Mistake Proofing is essentially mistake prevention. It allows workstations to achieve Six Sigma and stop defects from reaching the customer, but the defective part that was removed from the line still costs the company money and creates waste. So, the next step in Mistake Proofing is to find out why the part is defective in the first place and reduce the variability of the process associated with the production of that one part (George, 2002, p. 204).

Example:

It appears that Mistake Proofing focuses on one portion of the process and helps the team determine how to improve that one area. If we return to the Fishbone Diagram (Figure 19) that we have discussed previously, we see all of the variables associated with recycling rates. This example provides a simplified explanation of Mistake Proofing in a LEED-EB program. Since we identified that training had a significant impact on the recycling rate (as shown in Figure 24), we can attempt to increase the level of training that employees are receiving. The team will need to do the following: 1. Research the current method of training 2. Brainstorm options for increasing training numbers 3. Analyze impact of various options. Figure 26 shows the results of three types of training on recycling rates.

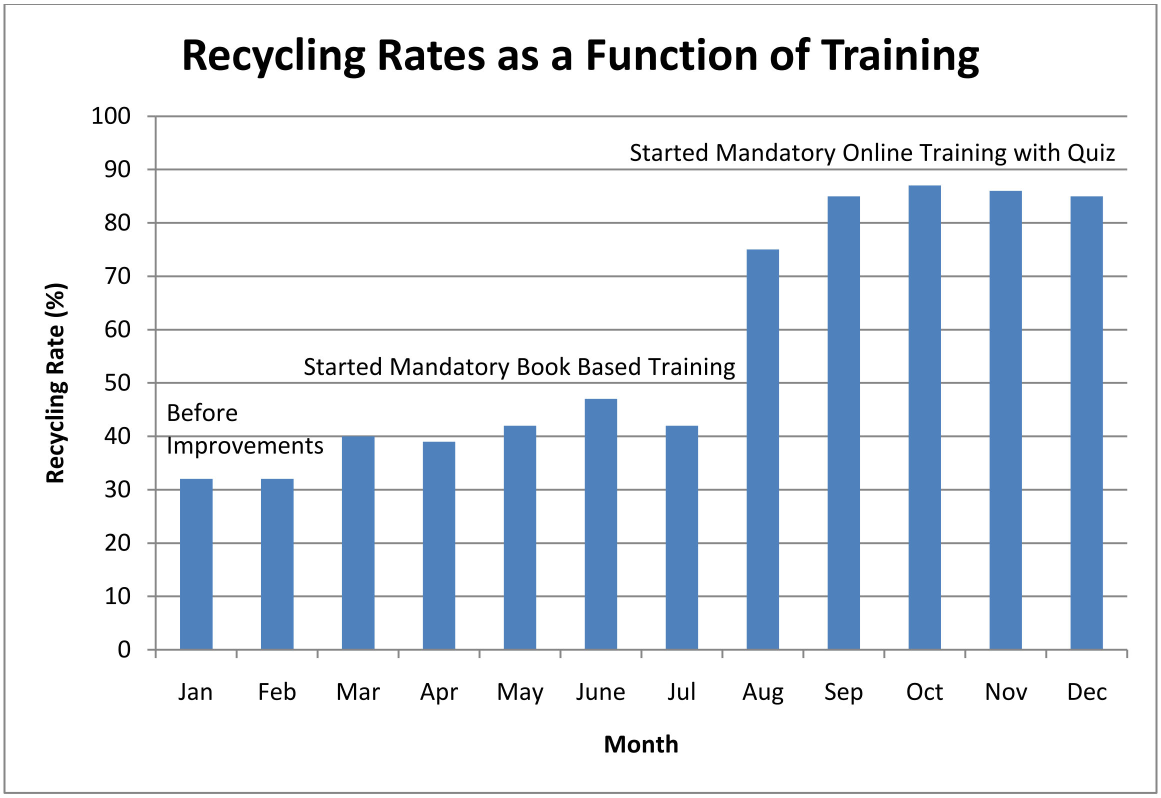

Figure 26. Mistake proofing for a LEED-EB recycling project.

Mistake Proofing can help teams identify if new procedures have the intended results. The example shown in Figure 27 indicates that with the implementation of mandatory online training, recycling rates have reached and exceeded the goal to recycling 80% of the materials used.

Kaizen.

Kaizen is "continuous improvement" in Japanese. It is modeled after quality circles, a team-based continuous improvement program which originated at Toyota. Kaizen involves intensive, rapid improvements. The Kaizen is a process that involves training, analysis, assessment, brainstorming, implementation, standardization, results, follow-up, parking lot (scoping ideas) and a final presentation. It is known for quickly generating momentum and energy to solve problems and make improvements.

Example:

Kaizen is a tool that could be used in LEED-EB to plan for the larger projects such as energy efficiency. Energy efficiency is one of the largest projects because there are many options for reducing energy consumption from building retrofits to occupant behavior. The Black Belt could initiate and facilitate the Kaizen event where Green Belts from various specialties join together to work on meeting the goals.

Control Phase.

Activities:

1. Develop Control Plan
2. Monitor Performance (12 Months)
3. Prepare and Submit Documentation for Certification
4. Mistake-Proof Process
5. Operate and Maintain

Check Sheets.

Check sheets were discussed previously under the Measure Phase. They would also apply to a LEED-EB project during the Control Phase.

Example:

Check Sheets during the control phase would include the operations and maintenance checks that are required for continued performance and monitoring of the programs and projects implemented. This is particular important for mechanical equipment that requires maintenance in order to continue to function as designed.

Run Charts and Control Charts.

Run Charts were discussed previously under the Measure Phase. They would also apply to a LEED-EB project during the Control Phase. Example:

Run Charts can be utilized during the control phase to monitor performance and locate any variance that may still need to be addressed.

Pareto Charts.

Pareto Charts were discussed previously under the Measure Phase. They would also apply to a LEED-EB project during the Control Phase. Example:

Pareto Charts can be utilized during the control phase to track improvements. Pareto Charts showing the baseline data can be compared with charts following improvements.

Summary.

In summary, Table 21 shows all of the Six Sigma tools discussed and which ones appear to be useful in implementing a LEED-EB program.

DMAIC Tollgates.

Another key to the DMAIC process are the Tollgates. A Tollgate follows each stage in DMAIC. This enables the team to regroup, discuss progress, brief the director and champions as well as other team members regarding the status of the initiative. Here is another option that a LEED-EB could employ. The following describes the review of the Tollgates which follow each step of the DMAIC process and how a LEED-EB project might implement it.

Define Tollgate.

At the end of the Define Phase, the team could hold a meeting with key players (Green Belts, Black Belts, Champions and Directors). They will discuss how/if the project definition was changed during the Define Phase and provide information on the impact to the value of the project as well as resources that will be required. They will begin plans for starting the Measure Phase (George, 2002, p. 174). Some of the questions that should be addressed during the Define Tollgate include the following (George, 2002, p. 174):

1. How was the project definition altered or refined (if at all)?
2. What evidence exists to confirm the value opportunity and resource requirements?
3. What is the team's plan for conducting the Measure Phase?

Measure Tollgate.

The Measure Phase Tollgate provides an opportunity for teams to present the results of the data collection and reporting. The reviewers, Black Belts, Champions and Managers, should ask the following questions (George, 2002, p.174):

1. Where did you obtain the data?
2. How is your measurement system?
3. What lessons did you take away from that data chart?
4. Can you show me your cause and effect diagram. How did you decide which of these causes to pursue with data collection? What data did you collect and what did you find out?
5. Why did you decide to collect that particular kind of data?

Analyze Tollgate.

The goal of the Analyze Phase is to make sense of all of the data collected during the Measure phase. When the team regroups following the analysis of all of the data, the questions that should be addressed includes the following (George, 2002, p. 175):

1. What causes is the team going to target in the Improve Phase?
2. Why did they focus on those causes? What are the links to the data/conclusions reached during the Measure Phase?
3. What other potential causes did the team investigate? How do they know those were not actual causes?

4. What data do they have that links the targeted cause to the problem under investigation?
5. What data indicates that improving the identified cause(s) will have the desired impact on the targeted improvement measure?

An additional issue that should be addressed in a LEED-EB project is authorization to move forward and a budget to complete the work. Because LEED-EB involves construction or installation that may require a significant investment, the Analysis Tollgate could also be utilized to sell the projects and obtain authorization and a budget to move forward.

Note that this is the point at which the failed LEED-EB project came off the tracks. The LEED-EB program had lost a significant amount of momentum, the tools used to communicate the results of the analysis and data were not the strong tools used by Six Sigma. The LEED-EB program did not have the strength that it might have had, had the team been following all of the Six Sigma methodologies that were previously discussed.

Improve Tollgate.

The Improve Tollgate is used to discuss the results of the focused projects, and some of the preliminary results of the upgrades. The questions that are addressed in the Improve Tollgate include the following (George, 2002, p. 176):

1. What countermeasures (projects) did the team develop?

2. How did they decide which ones (projects) to implement (e.g., criteria used to select among options, pilot tests used to see whether the changes had the desired effect)?
3. How do they know that those measures would affect the causes confirmed in Measure?
4. What happened when the countermeasures were first put into practice? What changes did the team make to refine the improvements?

Control Tollgate.

The goal of the Control Tollgate is to ensure that all of the progress made by implementing LEED-EB is sustained. Plans for future data and record keeping are discussed. The main questions addressed at the Control Tollgate are (George, 2002, p.177):

1. What indicators will be tracked to evaluate process performance?
2. Who will collect data on the indicators? Do they know what to do depending on what the data shows them?
3. What measures have been taken to ensure that all process staff / operators are trained in the new procedures and that any new staff will be similarly trained?
4. What best practices were established in the project? How are they being documented? What other lessons did the team learn? How is this information going to be shared?

Summary of Results

In summary, the results obtained from the review of the compatibility of Six Sigma methodologies and LEED-EB requirements had the following results:

1. Develop a phased approach for LEED-EB program. Phase 1 – The Foundation involves the foundational work, team building, executive participation and big picture goal setting.
2. Phase 2 – The Process involves utilizing the DMAIC process to select projects, collect data, analyze trends, determine solutions, target LEED credits, implement projects and initiate plans for the future.
3. Each of the tollgates discussed above provide a status update for all team members. The tollgates can be combined with the LEED-EB program and may show significant benefit in improving communication between team members and leadership as well as keeping the CEO's informed on the progress of the work.

Discussion of the Findings

The methodology that was investigated as a solution to the problem was: Determine if Six Sigma principles are compatible with the LEED-EB processes. The findings of the research support the suggestion that Six Sigma methodologies can be used to support a LEED-EB program. We can support this statement because the techniques used to implement a Six Sigma program can also be utilized by a LEED-EB program. Furthermore,

Table 8 provided a list of each of those Six Sigma goals that are accomplished under the Six Sigma LEED-EB program.

Six Sigma can be used to implement LEED-EB. Part 1 – The Foundation, prepares for a LEED-EB project, utilizing the Six Sigma techniques for building teams, ensuring upper management support, and ensuring that the culture of the company will embrace the changes required by the LEED-EB program. Part 2 – The Process, utilizes the Six Sigma tools and the DMAIC model. Every phase of the DMAIC model applies to requirements of a LEED-EB project and many of the tools used by Six Sigma are also applicable to LEED-EB projects. It is important to note that each and every step required for the LEED-EB program from initiation to standard operations cannot be added to the Six Sigma LEED-EB roadmap (Figure 27) because every project is different and requires that the team analyze projects in different ways. The step by step process map and procedures are generic enough that the tools of DMAIC can be implemented in ways that best serve the project goals. Finally, once, all of the changes have been implemented, the company can operate at with new sustainable, standard operating procedures (SOP).

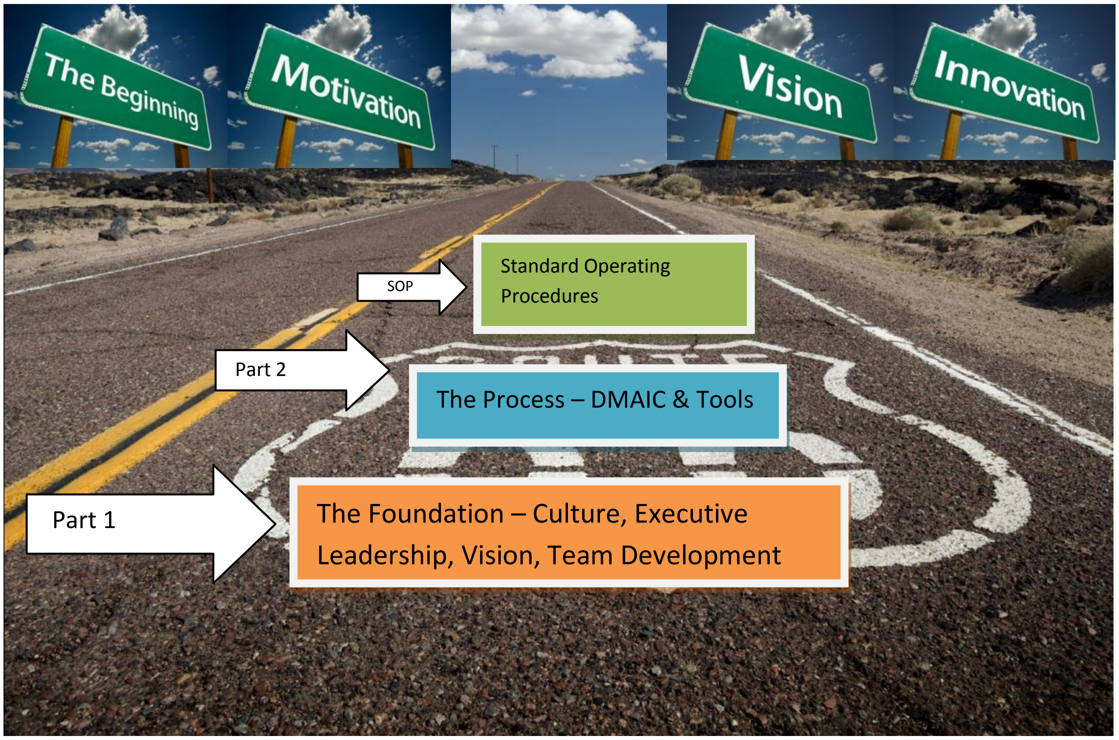

Figure 27. The Six Sigma LEED-EB road map.

Recall the barriers that Calia et al. (2009) had in implementing a pollution prevention program. Each of these barriers to implementing change in an organization is listed below. The anticipated ways that the Six Sigma LEED-EB program can reduce these barriers is provided below.

1. Insufficient decision-makers support to Pollution Prevention

    Solution: Part 1 – The Foundation requires that decision makers are involved from the beginning. Tollgate reviews ensure that progress reports and communication continues to engage the decision makers.

2. Organizational structures separating environmental decisions

    Solution: Preventative work performed during Part 1 of a LEED-EB project.

3. Lack of clarity about who should take on the leadership role in projects

    Solution: The Six Sigma LEED-EB road map includes a very well defined leadership hierarchy, assigning key tasks to team specialists such as the Green Belt – Mechanical specialists or the Champions assigned to remove roadblocks.

4. Resistance to change

    Solution: The Six Sigma LEED-EB road map works to ensure that the change will roll down from the top during Part 1 – The Foundation. A policy statement is developed and corporate goals are determined. With this level of leadership support of a program, change within the company is supported.

5. Insufficient employee accountability mechanisms

    Solution: Preventative work performed during Part 1 of a LEED-EB project.

6. Reward system not focused on Pollution Prevention

    Solution: Not addressed.

7. Fear that a Pollution Prevention project may jeopardize product quality

    Solution: With each of the statistical analysis tools available and the DMAIC process to guide the entire process, the team and work to ensure that any changes that are made within the company do not negatively impact any level of service or product produced.

8. Lack of information to recognize an opportunity for waste reduction

    Solution: Solution: Part 2 – The Process ensures that data is collected in some fashion.

9. Insufficient infra-structure to support Pollution Prevention plans

    Solution: Each of the plans required for LEED-EB

10. Poor internal communication

    Solution: Each of the plans required for LEED-EB

11. Conflicts and resistance to change

    Solution: Preventative work performed during Part 1 of a LEED-EB project.

12. Inflexible organizational structure

    Solution: Preventative work performed during Part 1 of a LEED-EB project.

13. Limited financial resources for capital improvements

    Solution: Not addressed.

14. Insufficient availability of time and personnel

    Solution: Preventative work performed during Part 1 of a LEED-EB project.

15. Concern that manufacture process change negatively impact quality

    Solution: Part 2 – The Process ensures that the only work that will be implemented is done so after a thorough analysis of all the potential impacts.

16. Concern of negative customers' perception about the product

    Solution: Not addressed.

17. Fear that the stability of the production system may be negatively changed by the Pollution Prevention project

    Solution: Solution: Part 2 – The Process ensures that the only work that will be implemented is done so after a thorough analysis of all the potential impacts.

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

Six Sigma methodologies have the capability to align with the goals and requirements of a LEED-EB project. It should be noted that Six Sigma is used to reduce variability or defects in a process. In a LEED-EB project, the defects being measured are not the outputs at the end of an assembly line, but rather the ability of a corporation to meet various sustainability objectives or benchmarks.

Objective Review

The following objectives were successfully achieved through the research and analysis performed by this thesis:

1. This thesis discusses the history and details of both the LEED-EB and Six Sigma programs.
2. A literature review of projects that have utilized Six Sigma including industries outside of manufacturing was performed. This thesis discusses the successes and failures of these programs.
3. An analysis of the compatibility of the Six Sigma methodologies and the LEED-EB programs was performed, including discussion of which Six Sigma tools and methodologies may be utilized as a technique by a LEED-EB project.

For objective 1, an understanding of both the LEED-EB program and Six Sigma methodologies was achieved through the review of existing literature. For objective 2, additional literature supported the theory that Six Sigma methodologies could be applied to a LEED-EB project. With research examples from several projects outside of the manufacturing industry, which is where Six Sigma originated, the notion that Six Sigma may be a useful approach for a LEED-EB project was supported. Finally, the third objective to perform an analysis of the compatibility of the two programs and determine how they might be merged into one was performed. Through this analysis, it was determined that there are many ways to implement both Six Sigma and a LEED-EB project. By following a very basic road map of building a foundation and then following the DMAIC process for LEED-EB, a Six Sigma LEED-EB program could be developed to support whatever goals for sustainability an organization may have. Many of the tools used on a Six Sigma project were analyzed and it was determined that such tools have direct application to the type of work that a LEED-EB project requires. One key component is communication and through the implementation of DMAIC tollgates which provide progress reports to all team members, momentum is maintained.

Recommendations for Further Study

Based on the results of this thesis, additional research could be performed to compare the benefits of utilizing a Six Sigma approach for LEED-EB versus a LEED-EB project that does not utilize Six Sigma methodologies. Areas to compare results include schedule, ability to meet goals, occupant satisfaction with end results, level of LEED certification achieved, total cost to implement LEED-EB, total operational savings and level of continued success of the program.

In conclusion, Six Sigma tools and methods can be applied to a LEED-EB project at each step, from the inception through operation. Based on the results of this thesis, additional research could be performed to compare the benefits of utilizing a Six Sigma approach for LEED-EB versus a LEED-EB project that does not utilize Six Sigma methodologies. Areas to compare results include schedule, ability to meet goals, occupant satisfaction with end results, level of LEED certification achieved, total cost to implement LEED-EB, total operational savings and level of continued success of the program.

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APPENDIX 1

USGBC LEED-EB CHECKLISTS

LEED 2009 for Existing Buildings: Operations & Maintenance
Project Scorecard

Project Name:
Project Address:

Yes	?	No			
0	0	0	**SUSTAINABLE SITES**		**26 Points**
			Credit 1	LEED Certified Design and Construction	4
			Credit 2	Building Exterior and Hardscape Management Plan	1
			Credit 3	Integrated Pest Management, Erosion Control, and Landscape Management Plan	1
			Credit 4	Alternative Commuting Transportation	3 to 15
				Reduce by 10%	3
				Reduce by 13.75%	4
				Reduce by 17.5%	5
				Reduce by 21.25%	6
				Reduce by 25%	7
				Reduce by 31.25%	8
				Reduce by 37.5%	9
				Reduce by 43.75%	10
				Reduce by 50%	11
				Reduce by 56.25%	12
				Reduce by 62.5%	13
				Reduce by 68.75%	14
				Reduce by 75%	15
			Credit 5	Site Development - Protect or Restore Open Habitat	1
			Credit 6	Stormwater Quantity Control	1
			Credit 7.1	Heat Island Reduction - Nonroof	1
			Credit 7.2	Heat Island Reduction - Roof	1
			Credit 8	Light Pollution Reduction	1

Yes	?	No			
0	0	0	**WATER EFFICIENCY**		**14 Points**
Y			Prereq 1	Minimum Indoor Plumbing Fixture and Fitting Efficiency	Required
0			Credit 1	Water Performance Measurement	1 to 2
				Whole building metering	1
				Submetering	2
			Credit 2	Additional Indoor Plumbing Fixture and Fitting Efficiency	1 to 5
				Reduce by 10%	1
				Reduce by 15%	2
				Reduce by 20%	3
				Reduce by 25%	4
				Reduce by 30%	5
			Credit 3	Water Efficient Landscaping	1 to 5
				Reduce by 50%	1
				Reduce by 62.5%	2
				Reduce by 75%	3
				Reduce by 87.5%	4
				Reduce by 100%	5
			Credit 4	Cooling Tower Water Management	1 to 2
				Chemical Management	1
				Non-Potable Water Source Use	1

APPENDIX 2

ENERGY STAR SAMPLE REORTS

ENERGY STAR

STATEMENT OF ENERGY PERFORMANCE

Building ID: 1505886
For 12-month Period Ending: February 28, 2009[1]
Date SEP becomes Ineligible: N/A

Date SEP Generated: March 24, 2009

1707 E. Highland
Phoenix, AZ 85016

1707 E. Highland
Phoenix, AZ 85016

Primary Contact for this Facility
N/A

Year Built: 1983
Gross Floor Area (ft^2): 63,410

Energy Performance Rating[2] (1-100) 68

Site Energy Use Summary[3]	
Electricity (kBtu)	4,285,397
Natural Gas (kBtu)[4]	0
Total Energy (kBtu)	4,285,397

Energy Intensity[5]	
Site (kBtu/ft²/yr)	68
Source (kBtu/ft²/yr)	226

Emissions (based on site energy use)	
Greenhouse Gas Emissions ($MtCO_2e$/year)	750

Electric Distribution Utility
Salt River Project

National Average Comparison	
National Average Site EUI	83
National Average Source EUI	278
% Difference from National Average Source EUI	-19%
Building Type	Office

Stamp of Certifying Professional

Based on the conditions observed at the time of my visit to this building, I certify that the information contained within this statement is accurate.

Meets Industry Standards[6] for Indoor Environmental Conditions:

Ventilation for Acceptable Indoor Air Quality	N/A
Acceptable Thermal Environmental Conditions	N/A
Adequate Illumination	N/A

Certifying Professional
N/A

Notes:
1. Application for the ENERGY STAR must be submitted to EPA within 4 months of the Period Ending date. Award of the ENERGY STAR is not final until approval is received from EPA.
2. The EPA Energy Performance Rating is based on total source energy. A rating of 75 is the minimum to be eligible for the ENERGY STAR.
3. Values represent energy consumption, annualized to a 12-month period.
4. Natural Gas values in units of volume (e.g. cubic feet) are converted to kBtu with adjustments made for elevation based on Facility zip code.
5. Values represent energy intensity, annualized to a 12-month period.
6. Based on Meeting ASHRAE Standard 62 for ventilation for acceptable indoor air quality, ASHRAE Standard 55 for thermal comfort, and IESNA Lighting Handbook for lighting quality.

The government estimates the average time needed to fill out this form is 6 hours (includes the time for entering energy data, PE facility inspection, and notarizing the SEP) and welcomes suggestions for reducing this level of effort. Send comments (referencing OMB control number) to the Director, Collection Strategies Division, U.S., EPA (2822T), 1200 Pennsylvania Ave., NW, Washington, D.C. 20460.

APPENDIX 3

CALCULATION SHEETS LEED-EB

Minimum Indoor Plumbing Fixture and Fitting Efficiency (WE Prerequisite 1)

Baseline Enter required info highlighted in yellow.

For a plumbing system substantially completed in 1993 or later throughout the building, the baseline is 120% of the water use that would result if all fixtures met the UPC 2006 Codes.

OR

For a plumbing system substancially completed before 1993 throughout the building, the baseline is 160% of the water use that would result if all fixtures met the UPC 2006 Codes.

Calculate the baseline water use of the building. It is based on fixture flow rates and estimated usage by the occupants. Use IPC or UPC 2006 for calculations.

Fixture	UPC and IPC Standard	US EPA Water Sense Standards
Water Closet (gpf)	1.6	1.28
Urinal (gpf)	1	0.5
Showerhead (gpm)	2.5	1.5-2.0
Public lavatory faucet and aerator (gpm) - 80psi	0.5	-
Public lavatory faucet and aerator (gpm) - 60psi	2.2	1.5
Public metering lavatory faucet (gallons per metering cycle)	0.25	-
Kitchen and janitor sink faucets	2.2	-
Metering faucets (gallons per cycle)	0.25	-

Equation 1: Occupants

Calculate the FTE. An 8 hour occupant has an FTE value of 1.0 and part-time and overtime ocupants have an FTE value based on their hours per day divided by 8. Estimate the number of transient occupants.

		FTE
Full Time Staff	210	210
Part Time Staff	7	3.5
Total		213.5

Estimate Number of Daily Transient Occupants

Transient Occupants	40

Table 3. Default Fixture Uses

Fixture Type	FTE	Student / Visitor	Retail Customer	Resident
	Uses/Day			
Water Closet				
*Female	3	0.5	0.2	5
*Male	1	0.1	0.1	5
Urinal				
*Female	0	0	0	na
*Male	2	0.4	0.1	na
Lavatory Faucet				
*Duration 15 sec; 12 sec with autocontrol	3	0.5	0.2	5
*Residential duration 60 sec	3	0.5	0.2	5
Shower				
*Duration 300 sec	0.1	0	0	1
*Residential duration 480 sec	0.1	0	0	1
Dish Washer				
*Per Use (15 gal/use)	0	0	0	na
Kitchen Sink				
*Duration 15 sec	1	0	0	na
*Residential duration 60 sec	na	na	na	4

Equation 2: Fixture Usage Groups

Group 1:	FTE	
Which fixtures are involved	water closet, urinal, lavatory faucet, kitchen sink,	
Which occupants they serve	FTE	
Year of substantial completion prior to 1993? (Y or N)	No	Double Check this... Marc Riddle contractr - said post 1993
Group 2:	Visitors	
Which fixtures are involved	water closet, urinal, lavatory faucet	
Which occupants they serve	Visitors	
Year of substantial completion prior to 1993? (Y or N)	No	

Note: If all accupants within the building have access to all fixtures, or if all fixtures are standard throughout the building, enter only a single fixture usage group.

Calculated the number of uses per day -

Calculations Based on This Facility (assuming 1:1 gender ratio): AUTOMATIC Calc

Fixture Type	FTE	Student / Visitor	Retail Customer	Resident
	Uses/Day			
Water Closet				
*Female	315	10		
*Male	105	2		
Urinal				
*Female	0	0		
*Male	210	8		
Lavatory Faucet				
*Duration 15 sec; 12 sec with autocontrol	630	20		
*Residential duration 60 sec	0	0		
Shower				
*Duration 300 sec	0	0		
*Residential duration 480 sec	0	0		
Dishwasher				
*Per Use (15 gal) x # dishwashers	4	0		manual calc
Kitchen Sink				
*Duration 15 sec	210	0		
*Residential duration 60 sec	0	0		

Baseline Case Water Consumption

This assumes 255 work days per year. The plumber stated that the existing fixtures are post 1993 therefore the 120% of the water use that would result if all fixtures met the 2006 IPC or UPC codes. Flow fixtures are used for 15 secs each. This calculation determines the maximum fixture water use allowed per prerequisite 1.

Flush Fixture	UPC 2006 Flow Rate (gpf)	This Facility USE per day	This Facility Water per DAY	This Facility Water per YEAR (Gallons)
Conventional Water Closet	1.6	432	691.2	176256
High-efficiency toilet (HET) single flush gravity	1.28	0	0	0
HET, single-flush pressure assist	1	0	0	0
HET, dual flush (full-flush)	1.6	0	0	0
HET, dual flush (low flush)	1.1	0	0	0
HET, foam flush	0.05	0	0	0
Nonwater toilet	0	0	0	0
Conventional urinal	1	218	218	55590
High-efficiency urinal (HEU)	0.5	0	0	0
Nonwater urinal	0	0	0	0
Sub Total		650	909.2	231846
Flow Fixture	**Flow Rate (gpm)**	**This Facility USE per day**	**Water per DAY**	**This Facility Water per YEAR (Gallons)**
Conventional private lavatory	2.2	650	357.5	91162.5
Conventional public lavatory	0.5	0	0	0
Conventional kitchen sink	2.2	210	115.5	29452.5
Low-flow kitchen sink	1.8	0	0	0
Conventional shower	2.5	0	0	0
Low-flow shower	1.8	0	0	0
Dishwasher (gallons per use)	15	60	60	15300
Sub Total		860	533	135915

UPC 2006 TOTAL (Gallons/Year)	**367,761**
BASELINE CASE: 120% of UPC 2006 TOTAL (Gallons/Year)	**441,313**

APPENDIX 4

ENERGY STAR DATA ENTRY CHECKLIST

Energy Star Evaluation
Request for Information

General Information

Project Name: ______________________

Project Address: ______________________

City: ______________________ State: __________ Zip: ________

____

Contact Name: ______________________ Phone: ( ) ______________________

Email: ______________________

Utility Bills

*Please provide a minimum of 12 consecutive months of energy consumption information. Invoices from your utility service provider for each meter will provide the required information (this includes gas and electric, etc.).

Space Type Information

*Please complete a space type worksheet for each space at your facility. Spaces include office, warehouse, parking lots etc.

Additional Information

*Additional information may be requested at a later time depending on which space types are provided on the following form.

Submittals

*Electronic copies of these forms and digital copies of utility bills can be emailed to____

Space Types

Instructions: Fill out one of these sheets for each space type at your facility. Space types include office, retail, warehouse, computer data center, parking, swimming pool, bank/financial institution, courthouse, hospital, hotel, K-12 school, medical office, residence hall/dormitory, retail, supermarket, multifamily housing, and other.

***Enter a Name for this Space (i.e. Office1):**

***Enter Space Type in space below (warehouse, hospital, retail, K-12, office, etc)**

***Year Built**

***Refrigerated or Unrefrigerated (enter in space below)**

Refrigerated buildings specifically designed to store perishable goods, manufactured products, raw materials, or merchandise under refrigeration. Included in this building type are cold storage facilities which store products at temperatures between 0 and 50 degrees Fahrenheit as well as freezer facilities which store products at temperatures between 0 and 20 degrees Fahrenheit. Unrefrigerated buildings are specifically designed to store perishable goods, manufactured products, raw materials, or merchandise without refrigeration.

Space Attribute	Space Attribute Value (Temporary values should only be used if actual value is not currently known.)	Use Default (Check box for default value)	Units	Effective Date (When this Attribute Value was first true) (MM/DD/YYYY)
Gross Floor Area		N/A	Sq. Ft	
Number of Workers	Temporary Use?		No Units	
Weekly operating hours	Temporary Use?		Hours	
Percent of the gross floor area that is cooled	Temporary Use? Select		%	
Percent of the gross floor area that is heated	Temporary Use? Select		%	
Number of walk-in refrigeration/freezer units	Temporary Use?		No Units	
Is building primarily lit by either high-intensity discharge or halogen lighting systems?	Temporary Use? No		No Units	
Number of PCs	Temporary Use?		Sq. Ft	
What percent of this space is air-conditioned?	Temporary Use? Select		No Units	
What percent of this space is heated?	Select For Temporary Use?		No Units	

APPENDIX 5

EQUEST CHECKLIST

Energy Simulation Data

General Information

Project Name: ____________________

Building Type: ____________________

Energy Code Compliance (check one) ☐ None ☐ California Title 24 ☐ Savings By Design

Building Location, Utilities and Rates

Coverage (check one) ☐ California Title 24 ☐ All Locations ☐ User Selected

Region/State: ____________________ City: ____________________

Utility Company: ____________________ Utility Rate: ____________________

Gas Company: ____________________ Gas Rate: ____________________

Area and Floors

Building Area: ____________________ ft^2

Number of Floors: ____________________

Number Above Grade: ____________________

Number Below Grade: ____________________

Cooling and Heating

Cooling Equipment (check one) ☐ No Cooling ☐ Chilled Water Coils ☐ Evaporative Coolers ☐ DX Coils

Heating Equipment (check one) ☐ No Heating ☐ Electric Resistance ☐ Hot Water Coils ☐ Furnace ☐ DX Coils (Heat Pump)

Other Data

Daylighting Controls (check one) ☐ Yes ☐ No

Usage Details (check one) ☐ Simplified Schedules ☐ Hourly Enduse Profiles

Analysis Year: ____________________

Building Envelope Constructions

Roof Surface - Construction (check one)

- ☐ Wood Advanced Frame, 24 in. o.c.
- ☐ Wood Advanced Frame, >24 in. o.c.
- ☐ Metal Frame, 24 in. o.c.
- ☐ Metal Frame, >24 in. o.c.
- ☐ Wood Standard Frame
- ☐ 2 in. Concrete
- ☐ 4 in. Concrete
- ☐ 6 in. Concrete
- ☐ 8 in. Concrete
- ☐ No Exterior Exposure (adiabatic)

Roof Surface - Exterior Finish (check one)

- ☐ Aluminum
- ☐ Marble
- ☐ Asphalt Pavement, Weathered
- ☐ Roof, Built Up
- ☐ Clay Tile
- ☐ Roofing, Shingle
- ☐ Concrete
- ☐ Steel, Galvanized (Bright)
- ☐ Felt, Bituminous
- ☐ Steel, Galvanized (Weathered)
- ☐ Film, Mylar Aluminized
- ☐ Vapor Deposited Low-e Coating
- ☐ Glass, Spandral
- ☐ Wood/Plywood
- ☐ Gravel
- ☐ Other: ____________________

Roof Surface - Exterior Color (check one)

- ☐ Uncolored
- ☐ Aluminum Paint
- ☐ Black, Flat
- ☐ Black, Gloss
- ☐ Black, Oil
- ☐ Blue, Dark
- ☐ Blue, Gloss
- ☐ Blue, Medium
- ☐ Blue-Gray, Dark
- ☐ Brown, Gloss
- ☐ Brown, Dark Brown
- ☐ Brown, Medium
- ☐ Brown, Medium Light
- ☐ Dark (abs=0.9)
- ☐ DEER 'Light' (abs=0.45)
- ☐ DEER 'Base' (abs=0.7)
- ☐ Gray, Dark
- ☐ Gray, Light Oil
- ☐ Green, Gloss
- ☐ Green, Gloss Dark
- ☐ Green, Light
- ☐ Green, Medium Dull
- ☐ Green, Medium Kelly
- ☐ Light (abs=0.4)
- ☐ Medium (abs=0.6)
- ☐ Olive, Dark Drab
- ☐ Orange, Medium
- ☐ Red, Oil
- ☐ Rust, Medium
- ☐ Silver
- ☐ White, Gloss
- ☐ White, Lacquer
- ☐ White, Semi-gloss
- ☐ Yellow

Roof Surface - Exterior Insulation (check one)

- ☐ No Ext.Board Insulation
- ☐ 1" polystyrene (R-4)
- ☐ 1" polyurethane (R-6)
- ☐ 1" polyisocyanurate (R-7)
- ☐ 1.5" polystyrene (R-6)
- ☐ 1.5" polyurethane (R-9)
- ☐ 1.5" polyisocyanurate (R-10.5)
- ☐ 2" polystyrene (R-8)
- ☐ 2" polyurethane (R-12)
- ☐ 2" polyisocyanurate (R-14)
- ☐ 3" polystyrene (R-12)
- ☐ 3" polyurethane (R-18)
- ☐ 3" polyisocyanurate (R-21)
- ☐ 4" polystyrene (R-20)
- ☐ 4" polyurethane (R-24)
- ☐ 4" polyisocyanurate (R-28)
- ☐ 5" polystyrene (R-25)
- ☐ 5" polyurethane (R-30)
- ☐ 5" polyisocyanurate (R-35)
- ☐ 6" polystyrene (R-30)
- ☐ 6" polyurethane (R-36)
- ☐ 6" polyisocyanurate (R-42)