SUSTAINABILITY ANALYSIS FOR

CONSTRUCTION COMPANIES

UNDER THE LEED CODE

by

WILLY ADAM GIRON MATUTE

ANDREW GRAETTINGER, COMMITTEE CHAIR
EDWARD BACK
CHUKWUMA NNAJI
BENNETT BEARDEN
PAULINE JOHNSON
GARY MOYNIHAN

A DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Civil, Construction, and Environmental Engineering
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2018

ABSTRACT

Sustainable construction is a very important input for economic development, improvement of human quality of living, and a major resource to decrease the negative impacts to our environment. While much published literature on sustainability really focuses on efforts made during a project's early concept planning and after it is built, there is little studies of construction phase actions. The lack of research suggests that sustainability during the construction phase of projects require more investigation, therefore the construction industry does not have enough measurable data to rely on.

In response to this need, the research related to construction is a must. The three main components of sustainability will be analyzed in favor of the construction industry. These main components of sustainability include the following aspects: environment, society and the economy. During the environment analysis, the relationship between sustainable new constructions inside United States compared to the rest of the world is compared. For the society aspect, an explanation of the relationship between the number of people certified to work in sustainable construction for different regions is presented. For the economy, the pricing relationship between CII (Construction Industry Index) sustainable construction measures are compared with traditional construction and the LEED code. Following the analysis of these three main categories, different results and conclusions are provided in favor of the construction industry.

DEDICATION

This dissertation is dedicated to my beloved parents, Mr. Wilfredo Giron and Mrs. Rosa Matute for their continuous support and advice through this journey called life.

LIST OF ABBREVIATIONS AND SYMBOLS

2-D	Two Dimension Modeling
3-D	Three Dimension Modeling
AD	Anderson-Darling
BD+C	Building Design and Construction
BLS	United States Bureau of Labor Statistics
BREEAM	Building Research Establishment Environmental Assessment Method
CAA	Clean Air Act
CII	Construction Industry Institute
CWA	Clean Water Act
DGNB	German Sustainable Building Council
EPA	Environmental Protection Agency
GDP	Gross Domestic Product
GIS	Geographic Information System
IEQ	Indoor Environmental Quality
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LDAR	Leak Detection and Repair
LEED	Leadership in Energy and Environmental Design
LEED AP	LEED Accredited Professional
LEED-EB	Leadership in Energy and Environmental Design for Existing Building

NIST	National Institute of Standards and Technology
PCB	Polychlorinated Biphenol
PV	Photovoltaic Solar Panel
POE	Post-Occupancy Evaluations
RCRA	Resource Conservation and Recovery Act
TRACI	Tool for the Reduction and Assessment of Chemical and other Environmental Impact
UAE	United Arab Emirates
US	United States of America
USGBC	United States Green Building Council
VOC	Volatile Organic Compound

ACKNOWLEDGEMENTS

I am pleased to have this opportunity to thank the many colleagues, friends, and faculty members who provided help during the creation of this dissertation. I am most indebted to Dr. Andrew Graettinger, the chairman of my dissertation, for sharing his research expertise and wisdom in relation to my work and studies. I would also like to thank all of my committee members for their invaluable input, inspiring questions, and support of both the dissertation and my academic progress. Thank you, Dr. Edward Back, Dr. Chukwuma Nnaji, Dr. Bennett Bearden, Dr. Pauline Johnson, and Dr. Gary Moynihan, for the time they committed in serving in my committee and for the invaluable assistance to make my dissertation to what it is today.

I will also like to thank The University of Alabama for giving me the opportunity and support to present my dissertation in Civil Engineering with a focus on Construction Management. I also want to include and give thanks to organizations such as the National Science Foundation (NSF) and the Alabama Department of Transportation (ALADOT) for funding part of my studies and believing in the work that we do in cooperation with The University of Alabama.

Lastly, I would like to thank the Lord Jesus Christ, without him no work would be possible. He provided me with strength to finish this dissertation. Thank you, Lord, for your abundant blessings!

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

This chapter presents an overview of sustainability in the construction industry and shows how Leadership in Energy and Environmental Design (LEED) is related to today's construction. The research objectives will be explained in detail and the motivation for this work will be presented. The organization of this dissertation is described in this chapter for easier understanding for the reader. This chapter provides an outline of the dissertation and creates the structure of the research in subdivisions.

1.1 Background

Today, deteriorating infrastructure and limited research is impeding the ability to compete in the thriving global economy, improvements are necessary to ensure the United States is built for the future. While there is some progress, reversing the trajectory after decades of underinvestment in the infrastructure requires transformative action from the different states, infrastructure owners, local authorities, and the American people. Both research and work are immediately needed to improve construction and protect future generations inside the United States. The United States needs to commit today to realize an American infrastructure system that secures the nations shared prosperity.

In recent years, sustainability has become a significant matter for the construction industry. Thus, an increasing proportion of construction budgets have been used to improve the construction process using sustainability norms and techniques. Sustainability in construction refers to the use of processes that are environmentally responsible and resource-efficient throughout a building's life cycle (Harper, 2017). Sustainability has risen as a tool in construction over the last years to decrease life-cycle costs. Sustainability, or green construction, has become a very important factor for the construction industry in the United States. Different organizations are focused on improving environmental conservation through green construction. Efforts are underway to identify new forms of construction that improve the quality of life.

The U.S. Green Building Council (USGBC) is an organization that works to improve the current standards of construction by means of sustainability. The USGBC developed a sustainability code for construction, the LEED code. Leadership in Energy and Environmental Design (LEED) is composed of a rating system for the design, construction, and maintenance of buildings in the United States. LEED aims in helping the construction industry to be environmentally responsible and use resources wisely and more efficiently.

The LEED code is the first step to create a balance between the environment, economy, and society. LEED is the most widely known sustainable construction certification program used in the United States. The building types included under the LEED rating system are: homes, neighborhoods, schools, hospitals, and human habitable structures in general. LEED aims to promote environmentally responsible construction and use resources more efficiently. The U.S. Green Building Council is committed to scale LEED sustainable buildings to more than 5 billion square feet by the end of year 2020 ("LEED Green Building", 2009).

Both buildings and people can be certified by LEED. For example, new construction such as a house or a commercial building can apply to the LEED process to be certified. Once the construction is completed, the USGBC will grant a permit to display the official USGBC logos inside the new construction. These logos are generally placed at sites once an inspection of the building is completed. Inspectors certified by LEED, can testify that the building is under acceptable LEED conditions. Figure 1.1 shows an example of the USGBC official logo at the Children's Hospital in Birmingham, AL.

Figure 1.1: USGBC Logos in the Children's Hospital

1.2 Research Objectives

Currently, LEED is mostly used as a norm for sustainability and life cycle cost reductions in the United States. Those who are in favor of LEED believe that following this process can make a difference for the environment and improve the quality of life in our society. On the other side, is the belief that using LEED is a waste of time and resources for the construction industry. There is a general belief that LEED is mainly used for personal profit rather than to promote sustainability and green construction. This dissertation will provide a sustainability analysis inside the construction industry by using the LEED code. The construction industry is very interested in how sustainability can reduce the waste of resources and increase the life span of the buildings, but are they willing to pay the additional costs associated with LEED? Is it economically feasible for the construction industry to do the extra work and training to enhance sustainability?

The main objective of this dissertation is to evaluate how sustainability, promoted by the LEED code, is impacting the construction industry by improving the environment, society, and the economy.

The following activities are included in the dissertation to accomplish the main objective:

- Create a profile of where LEED New Construction currently stands in the United States (US) compared to the rest of the world.
- Testing and statistical analysis of LEED New Construction inside and outside the US.
- Big data statistical analysis for people practicing LEED inside and outside the US.
- Provide recommendations and sustainable activities that can benefit construction companies.
- Find the relationship between the number of people certified under the LEED code in the US and around the globe.
- 3-Dimension Simulation of LEED certified personnel by geographic area.
- Create a quantifiable economic relationship between sustainable and traditional construction inside a construction firm.

1. 3 Problems and Research Statement

Different problems in the construction industry include unemployment, rapid loss of natural resources, and lack of access to measurable data. One of the purposes of this dissertation is to identify the effect of LEED certification in construction and provide new research for construction companies to improve their sustainable focus while doing business. The problem statement addresses the need to transform the way buildings are designed and operated to enable a healthier and more socially responsible environment without considerably increasing the costs.

Three research questions are defined to form the core of the dissertation to be presented:

- *Question#1 Environment:* How strong is the relationship between sustainable new construction in the US when compared to the rest of the world? A rigorous analysis through different statistical methods that probe the relationship between the increase of new construction inside the US compared to other countries under the LEED code.
- *Question#2 Society:* What is the relationship between LEED certified people inside and outside the US? A visualization test using maps that can probe the relationship between the increase of LEED certified personnel working in green construction inside and outside the US is presented.
- Question#3 *Economy*: From a construction company point of view, what is the economic relationship between sustainable and traditional construction? A case study will be performed by analyzing the Construction Industry Index (CII) Sustainable Practices for labor. The type of labor will include in-house work and subcontracting elements for construction, when available. The difference between working with a sustainable focus compared to a traditional work is performed and the results are analyzed.

After answering these three questions, the dissertation will be able to provide a complete update on sustainability in relation to the environment, society and economic aspects inside the construction industry. Figure 1.2 explains the hierarchy of the dissertation work.

Figure 1.2: Dissertation Hierarchy

1.4 Dissertation Organization

This dissertation provides results of research on implementing sustainability in construction companies through the utilization of the LEED code. The dissertation is structured and outlined in the following format:

Chapter 1: Provides an overview of construction today. In this chapter, the research objectives are defined and the initial insight of why this research was developed is explained. During this chapter, a framework for the complete dissertation is presented in subdivisions.

Chapter 2: Presents a summary of terminology and scientific terms that are needed to understand the dissertation. The literature review is a report of information that is related to the selected area of study for this dissertation. The LEED structure is defined, other related studies are presented, and the advantages/disadvantages of sustainability in the construction industry are provided.

Chapter 3: Provides the research methodology adopted during this dissertation. The scope of work and hypothesis are presented in a more detailed description. The type of data used for the dissertation is organized into the three different elements of sustainability: environment, society, and economy.

Chapter 4: This chapter includes the analysis performed to measure the impact of sustainability in the environment, when comparing LEED New Construction inside and outside US.

Chapter 5: This chapter includes the analysis performed to measure the impact of sustainability over society, when defining the relation between LEED personnel around the globe.

Chapter 6: This chapter includes the analysis performed to measure the economic impact of sustainability inside construction companies.

Chapter 7: Results and conclusions of the dissertation are organized in this chapter, this includes the impact that sustainability may have over the environment, society and economy. Summarizes the findings during the dissertation and provides the conclusions of the work done. Limitations of the research, future research extensions and new opportunities are discussed.

CHAPTER 2

LITERATURE REVIEW

Sustainable construction is an important input for economic development, improvement of quality of life, and a driving force to decrease the impact on our environment. The following subjects will be explained and defined in order to better understand the role of LEED in our context. Terms such as green building, LEED process, and previous studies will be explored for better understanding of the dissertation.

2.1 Sustainability

Sustainable construction, also known as green construction or green building, refers to the use of environmental techniques that are economically efficient throughout a building's life cycle (Edminster, 2010). This includes different stages of a project such as design and construction. After the project is complete the operation and maintenance can also be included as part of the sustainable focus. Green building involves finding the balance between construction and the environment. A sustainable focus also requires the help of the members working on the project. This includes the following: design team, engineers, project manager, and the client. Sustainability considers every person working on a project at every stage. The practice of green building will expand and complement the classic building design concerns of economy, utility, durability, safety, and comfort (Kibert, 2010).

Although new technologies are constantly being developed or updated to complement current construction techniques to create a more sustainable structure, the basic objective of green building is to reduce the overall impact produced by construction and improve human health and environment. Some green building programs do not address the issue of retrofitting existing homes, but others do, especially through public projects for energy efficient refurbishment. Green construction principles can easily be applied to new buildings and already developed construction. One very common application of green construction is to produce electricity using photovoltaic (PV) solar panels. Figure 2.1 shows an example of solar panels to power the irrigation system of multiple gardens in Hoover, AL. These gardens are located in an area were no electrical grid is available. The best form to power the irrigation system of these gardens is utilizing an independent power source through PV solar panels.

Figure 2.1: Solar Panels providing electricity for a garden in Hoover, AL

2.2 Concepts

Sustainable construction aims to meet present day needs for housing, working environments, and infrastructure without compromising the ability of future generations to meet their own needs in times to come (CEEQUAL, 2008). Sustainability includes different terms to improve the elements of economic efficiency, social responsibility, and the performance of the environment. Concepts such as sustainable development, sustainability, green construction, and life cycle assessment will be presented to show the relationship between these terms.

Sustainable development is maintaining natural resources and ecosystem development while meeting society's economic goals (Lindley, 2012). Sustainable development and green buildings are related but are not the same. To achieve sustainable development, certain criteria within a framework of economic, environmental, and social systems must be accomplished. Life cycle assessment (LCA) analysis is present in all the stages of sustainable development. These stages include: design, construction of the building, maintenance and operation, and disposal. Figure 2.2 and 2.3 relate the sustainable terms used during this dissertation.

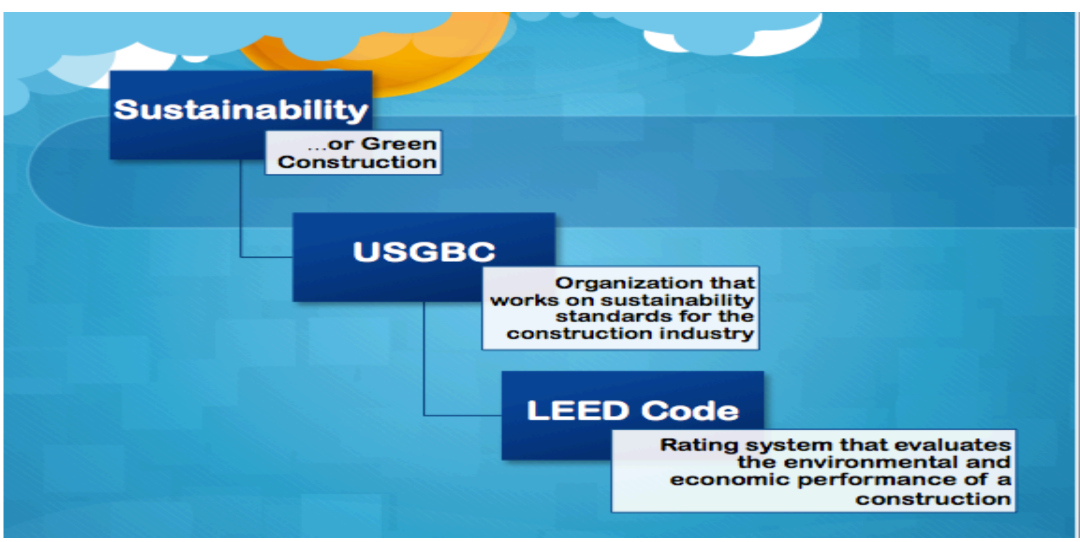


Figure 2.2: Relation between Sustainability, Green Construction, USGBC, and LEED

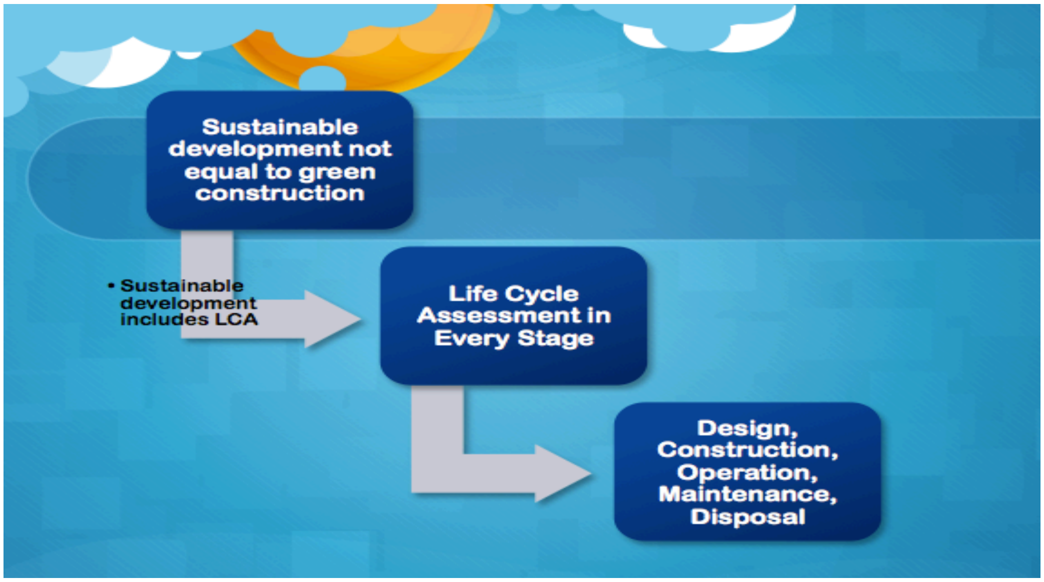


Figure 2.3 Relation between Sustainable Development and LCA

2.3 LEED

Leadership in Energy and Environmental Design (LEED) is a rating system device that evaluates the environmental performance of a building and encourages market transformation toward consuming less energy. The main goal is to help builders, architects, and civil engineers to be environmentally responsible and maximize the use of resources ("LEED Green Building", 2009).

LEED is designed for all buildings, from homes to corporate headquarters, at all phases of development, including maintenance. Projects pursuing LEED certification earn points through several areas that address sustainability issues. Based on the number of points achieved, a project then receives one of four LEED rating levels. The ratings for LEED are the following: Certified, Silver, Gold, and Platinum. Certified is the least amount of points the building can get and Platinum certification is the highest amount of points a building can achieve ("LEED Green Building", 2009).

2.3.1 LEED Structure

LEED building certification is completely voluntary, but sometimes certification is a requirement for government projects. Based on existing and proven technology, LEED will evaluate the environmental performance from a whole building perspective over a building's life cycle. A building life cycle refers to the view of a building over the course of the entire life. This includes the construction, operation, demolition, and waste treatment of the building.

LEED methods provide a definitive standard for what constitutes a green building in design, construction, operation, and management. Every rating system category is designed to scale to new and existing commercial buildings, institutions, retail, hospitals, and residences.

LEED is based on proven energy and environmental principles. It creates a balance between established practices and new concepts. Each rating system is organized into six different environmental categories:

- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation in Design

The Innovation in Design category is new and possess a major focus in sustainable building expertise, as well as design measures not covered under the previous five categories. An additional category is LEED Regions, this extra section rewards the importance of local conditions in determining best environmental practices for construction. All the points awarded under this last category are considered bonus points (Raulerson, 2012). Figure 2.4 shows an example of LEED category logos used to certify a building. Each logo describes a different category of LEED: water efficiency, energy & atmosphere, materials & resources, and indoor environmental quality.

Figure 2.4: LEED Category Logos

2.3.2 LEED Scoring

LEED scoring is made by the sum of credits based on the potential environmental impact and human benefits by each category inside the LEED code. The environmental impact is defined by the human effect of the design, construction, and maintenance of the building. This includes different aspects that impact the environment such as carbon dioxide emissions, fossil fuel use, toxins and carcinogens, air and water pollutants, or indoor air quality conditions. A combination of approaches, including energy modeling, life-cycle assessment, and transportation analysis, are used to quantify each type of impact. All credits for a project sum to the credit weight ("LEED Green Building", 2009).

LEED code uses the U.S. Environmental Protection Agency's TRACI (tool for the reduction and assessment of chemical and other environmental impact) categories as the basis for weight of each credit. The initial objective of TRACI was to assist with the impact evaluation for life-cycle analysis for buildings, process design, and pollution prevention. For example, LEED code version 2009 takes into consideration the weightings developed by the National Institute of Standards and Technology (NIST). Together, the two approaches provide a complete structure for determining the value of each credit.

The LEED credit weightings process is based on the following:

- LEED credits are positive, whole numbers.
- The credits have no fractions or negative values.
- Credits receive a single status (no individualized scorecards).
- A LEED rating system contains one hundred (100) base points. Extra credits can be accomplished through Innovation in Design and Regional Priority categories. These categories provide opportunities for up to ten (10) bonus points.
- All LEED credits are worth a minimum of 1 point.

Each credit is allocated points based on the relative importance of the building-related impacts that it addresses. The result is a weighted average that combines building impacts and the relative value of the impact categories. Credits that directly address the most important impacts are given the highest weight. Credit weights also reflect a decision by LEED to recognize the market implications of point allocation.

The credit weighting process involves three basic steps:

- A reference building is used to estimate the environmental impacts in 13 categories associated with a typical building pursuing LEED certification.
- The relative importance of the impact in buildings for each category is set to reflect values based on the weightings.

- Data that quantify building impacts on environmental and human health are used to assign points to individual credits. (Retzlaf, 2008)

During the credit weight process, one (1) point is assigned if a LEED accredited person is working on a project. In order to get certified as a LEED person, a successful examination in the appropriate building type must be completed. The examination content includes everything related to sustainable construction and the requirements to get a building certified. Currently, LEED does not require a university degree to be able to acquire LEED certification. Figure 2.5 is an example of a LEED certification diploma. The figure shows a LEED Green Associate certification, which is the first step in the accreditation process for contractors and designers interested in sustainable construction.

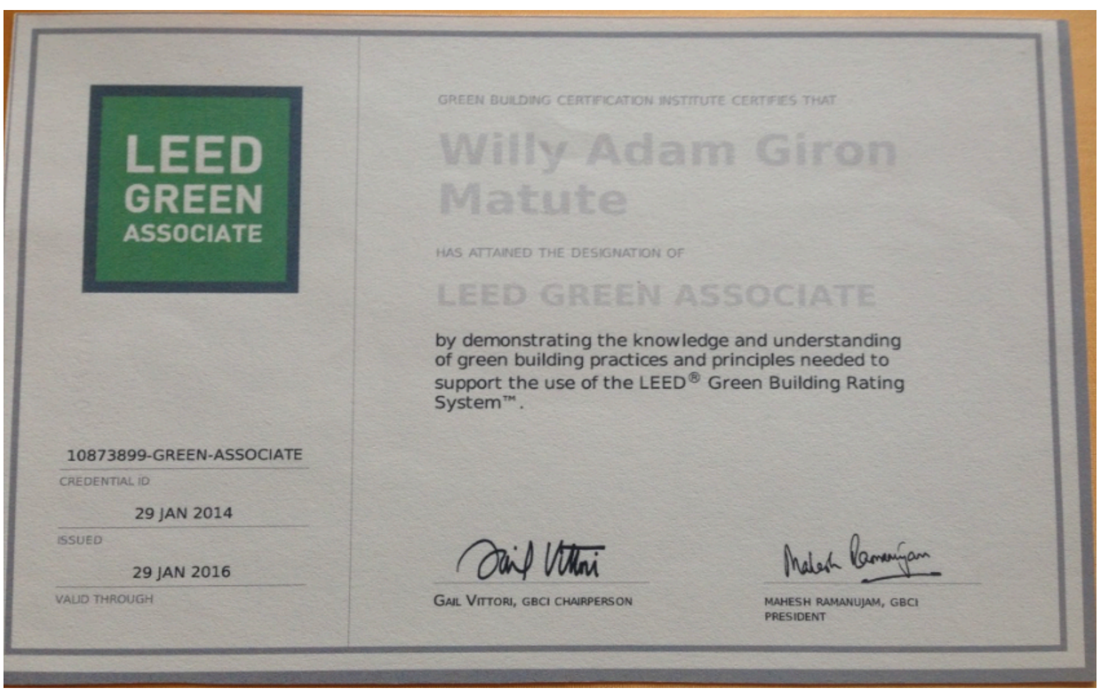


Figure 2.5: LEED Green Associate Certification

2.3.3 LEED Today

LEED is a measuring tool for green buildings that is used in the United States and other countries around the globe. Countries such as Canada, India, China, and Brazil are also using the LEED code in recent years. However, LEED certified buildings have been slower to enter in smaller markets. The main reason of the slow movement outside the United States is because LEED cannot be applied equally to different environmental conditions. For example, a building located in the northeast of the United States would receive the same credit as a building in California for water conservation, even though the principle is more important in places with water shortages. Also, criticism of the code comes from the cost of LEED certifications and diplomas. Every certification in LEED has a fee that needs to be paid to the USGBC before starting a project. This money could be used to make a building more sustainable, instead of using the money to pay fees for a certification. Many critics have noted that compliance and certification costs have grown faster every year at the USGBC (Gifford, 2010).

Energy conservation is one of the weakest aspects in the LEED evaluation. A review from the newspaper, USA Today showed that most projects target easy and less expensive green points. Few owners adopt renewable energy because of the high costs associated with power generation. A common sustainable power generation option is solar panels. Solar panels are renewable energy providers, but the system and installation will generally increase the project cost by a large margin (Gifford, 2010).

Today, the USGBC have new subdivisions for different construction projects. One example of these subdivisions is LEED-EB (Existing Buildings). This type of buildings (LEED-EB) can achieve superior operating cost savings in more than 63% of the cases by retrofitting an existing building using sustainable techniques (Boeing, 2014). The implementation of this system is less expensive and possesses good potential savings for life-cycle costs. Figure 2.6 shows an example of an existing building that acquired a LEED certification in New York. The Grand Central Terminal in New York, is an old building that went through a major renovation to be certified by LEED. The Grand Central is an example of a LEED Existing Building (EB).

Figure 2.6: LEED-EB: Grand Central Terminal, NY

LEED is a design tool and not a performance measurement tool. It is also not climate specific, although the newest version hopes to address this weakness. LEED is also not energy specific, it only measures the overall performance. Contractors and designers are free to choose how to achieve points under various categories (Chasey et al., 2012).

The construction industry has proven to be durable and able to withstand economic hardships. Both the residential and commercial sectors experienced growth since the recession of 2009. Overall there has been an increase in the construction market in recent years, and these jobs contribute to an increase in the gross domestic product (GDP). Although the growth of the construction industry has mirrored that of the overall economy since 2009, there has been a steady increase in investments and bank lending. Therefore, the possibility of more sustained economic development that positively affects construction is increasing (Diesendorf, 2000).

Green construction represents a portion of building activity as a whole and its growth rate has outpaced general construction over the past few years. The green construction market is expected to continue its growth in the coming years due to sustained investment in green technologies, manageable inflation rates, increased government infrastructure spending, declines in long-term interest rates, and a steady market signal for green construction and resale value.

2.3.4. Laws Related to LEED

Local and national policy has continued to support green construction and renovation due to multiple drivers such as changes in code, state, and national emphasis on energy efficiency, greenhouse gas reduction, and creating more jobs domestically. LEED is a market leader of green construction and continues to be a key influencer of widespread green construction adoption. Economic and social benefits to owners and occupants, incentivized utility programs, decreased lifecycle costs, and increased asset value are among the reasons that companies and individuals choose to build LEED-certified buildings (Bennick, 2011).

Construction must comply with applicable federal, state, and local laws. In order to apply sustainable techniques, different environmental laws and conditions must be taken into consideration during the construction process:

- TRACI is an environmental impact assessment tool. It provides characterization factors for Life Cycle Impact Assessment (LCIA), industrial ecology, and sustainability metrics. Characterization factors quantify the potential impacts that inputs and releases have on specific impact categories in common equivalence units. Impact categories include:

ozone depletion, climate change, acidification, eutrophication, smog formation, and human health impacts.

- Clean Water Act (CWA): This specific law is important to restore and maintain the nation's waters by preventing point and nonpoint pollution sources. Also, to discharge storm water runoff a permit is required from the Environmental Protection Agency (EPA).
- Resource Conservation and Recovery Act (RCRA): This regulation contains requirements for managing and specifications to transport hazardous wastes. Fluorescent lamps that contain mercury and polychlorinated biphenol (PCB) are included under this regulation. Upon construction or demolition, PCBs waste material regulations are specified through the RCRA.
- Clean Air Act (CAA): The CAA is the federal law designed to control air pollution. The Act requires industrial facilities to implement a Leak Detection and Repair (LDAR) program to monitor and audit a facility's emissions of volatile organic compounds (VOC).

These specific laws mentioned are related to the LEED code in order to protect the environment and improve sustainability in construction and are considered when designing a green building or structure.

2.4 Sustainability Today

Green construction is a relatively new topic and there is a limited amount of information distributed to the general public. In recent years, instead of increasing the knowledge associated with sustainability, there has been a cut for funds that were originally destined to improve resources in sustainability. A good example of this involves recent government administration cuts. On March 1, 2013, the Obama administration cut 5% of the total budget for the Bureau of Labor Statistics (BLS). In order to reorganize their funding, the BLS decided to eliminate information related to measuring green jobs. To achieve savings and protect core programs, the BLS was obligated to eliminate statistical data for the coming years related to sustainability (US Bureau of Labor Statistics). The products and data that were eliminated from the system included:

- Data on employment by industry that produce green goods and services
- Data on occupation for businesses that produce green goods and services
- Information related to wages of jobs related to green technologies and practices
- Green career information publications

The cuts in funding in the area of sustainability shows the need for this type of dissertation research.

Today, different activities need to be implemented in order to accommodate sustainable construction in the current traditional techniques employed to build structures:

- To achieve cost reduction, sustainability proposes a complete design of the project before the construction stage. Additional expenses in construction result from poor planning and delays. Organization and including all stakeholders from the very beginning of the project will minimize the amount of delays during the construction stage (Bennick, 2011).
- Lean construction stands for using the minimal amount of resources to complete a construction project. Sustainability focus includes the decrease, recycle and reuse of

materials and waste during the construction stage of the project under a lean construction emphasis (Berkemeyer and Robbins, 2008).

- Materials designated for green construction are generally more expensive than traditional materials. Once the material technology becomes widely used, the price of the green product will be lower.
- The percentage of people certified or trained on sustainable construction is low. To achieve a sustainable focus, labor will need to be trained under the LEED code. Consequently, prices for training and labor will always stay high. To reduce the prices of training, more people will need to be involved in the sustainable focus.

Following the above recommendations can help improve sustainability today and take advantage of the benefits under the LEED code.

2.5 Advantages and Disadvantages of Sustainability

In the long term, green building makes sense, but in the short term it may be difficult for construction firms to take the risk of working with sustainable practices. A big part of the construction budget is assigned toward construction in order to achieve LEED requirements. The additional expenses may be hard to process for construction companies. Below are the main reasons that positively and negatively impact the construction industry under a sustainable focus:

Positive

- Upfront investment in green building makes properties more valuable, with an average expected increase in value of 4%. Green construction will try to lower maintenance and energy cost and will provide a return on the investment on the following years after the construction stage. Owners are more likely to invest in construction if they think about the long-term benefits of green construction, therefore increasing the number of construction project opportunities (Schiavon and Altomonte, 2013).

- Green building retrofit projects generally decrease operation costs by almost 10% on the first year (Newsham, et al., 2009). Using a sustainable focus can help increase profit margins in construction. Instead of demolishing and starting a new project from scratch, a building can be retrofitted under a sustainable focus and use less resources for materials and equipment to increase the margins of profit in construction activities. Construction firms do not need to limit themselves to new projects only. Construction firms can offer remodeling and retrofitting services for existing homes and buildings to increase their revenues.
- Standard building practices generally use tons of material waste every year. On the other hand, green building uses fewer resources and tries to minimize waste. Currently, LEED projects are responsible for diverting more than 80 million tons of waste from landfills. In construction, if the amount of resources is decreased or reused, this will help increase the profits and maximize the resources inside a construction firm (Azevedo and Morgan, 2012).
- Adding sustainable construction to a company's capabilities can create a market advantage for the construction firm and increase the percentage of financial success. A growing demand for green projects presents an opportunity to generate additional revenues for construction firms. If green construction is one of the capabilities inside a firm, the business is more diverse.

- As a construction firm, different tax credits and incentives on the federal, state and local levels are designed to fund green building initiatives. Construction firms can take advantage of these credits.
- LEED code proposes the reduction of chemicals used in different construction materials. This will eventually improve the safety and health of construction workers at the site.

Negative

- Sustainable focus is always associated with additional fees to achieve any level of certification. LEED code includes high fees for registration and certification along with commissioning fees.
- New technology and green materials will tend to have higher prices. This will increase the budget of a construction project.
- Finding labor that is certified in green technology installation can be difficult and additional fees are associated for training.
- Time is money and implementing the LEED code in construction is time consuming. It takes time to understand and be familiar with the LEED code.
- Sustainability is designed to reduce life cycle costs, so it will help reduce long-term expenses for the owner. Generally, a construction firm will not see the benefit of an increased budget for sustainability.

These practices are considered the main positive and negative reasons of why sustainable techniques should be implemented in construction companies.

2.6 Other Studies

Sustainability may be defined as meeting the needs of present generations without compromising the ability of future generations to meet their needs (UN, 2012). Different scientists have tried to find benefits that green construction produces in short and long terms for human health and the environment. For example in 2013, Schiavon and Altomonte developed a study on indoor environmental quality and the potential health benefits of green certified buildings. The study showed that green buildings provide better indoor environmental quality than regular buildings. Green buildings possess direct benefits to human health for occupants in comparison to non-green buildings. Also, Newsham et al. (2013) published a detailed study on indoor environment quality (IEQ) and LEED buildings. Field studies and Post-Occupancy Evaluations (POE) were performed in twelve (12) green and twelve (12) conventional buildings across Canada and the northern United States. The feedback was very positive in the areas of environmental satisfaction, satisfaction with thermal conditions, aesthetic appearance, reduced disturbance from heating, ventilation and air-conditioning noise, workplace image, mood, and reduced number of airborne particulates. The results showed green buildings exhibited superior performance compared with similar conventional buildings.

Other studies demonstrated the benefits of green construction by lowering the consumption of energy in the buildings. In 2009, Newsham et al. showed the savings produced by green buildings versus conventional buildings related to energy usage. After reviewing sixty (60) LEED buildings they found that on average, LEED buildings are 25-30% more energy efficient than conventional buildings. Results show that the increase of efficiency came from the increased productivity from better ventilation, temperature control, and lighting measures.

As of 2010, an Energy Star system was also analyzed to estimate the benefits it produces in operations and management. Energy Star is a similar system to LEED, but it only focuses on energy optimization. Buildings evaluated through Energy Star, from a purely financial perspective, demonstrated that rental office space generally charged higher rent and had higher occupancy rates. The certified buildings achieve significantly higher rents, sale prices and occupancy rates as well as lower capitalization rates. This will also create lower investment risk for the investors (Fuertes and Schiavon, 2015).

When a LEED rating is pursued, the cost of initial design and construction rises. There may also be a lack of construction components that meet LEED specifications. Pursuing LEED certification for a project is an added cost in itself. This added cost comes in the form of USGBC fees, hiring a LEED consultant, and certification costs. However, these higher initial costs can be effectively mitigated by the savings incurred over time due to the lower operational costs typical of LEED certified construction. Also, additional economic payback may come in the form of employee productivity gains incurred as a result of working in a healthier environment. In 2003, a study from Kats et al. suggests that an initial up-front investment of 2% extra focusing in sustainability yields over ten times that initial investment over the life cycle of the building.

This dissertation is similar to other studies because this work examines how sustainability is positioned in construction, but this dissertation is different because it analyzes how sustainability impacts the construction industry through LEED. While much published literature on sustainability focuses on efforts made during a project's early concept planning and after it is built, there are few studies of the actions during the construction phase. The lack of research suggests that sustainability during the construction phase of projects require more investigation, therefore the construction industry does not have enough measurable data to rely on.

CHAPTER 3

METHODOLOGY

Chapter 3 defines the foundation of this dissertation by describing in detail how the research methodology is organized in three main components: society, economy, and environment. The main objective, scope of work, and hypothesis are presented and discussed in detail. The research framework presents the different subdivisions that the dissertation is responding. Finally, the different sets of data and sources are presented to the reader.

3.1 Objective

The main objective of this dissertation is to evaluate the effectiveness of sustainability, for the construction industry to improve the environment, society, and the economy through the LEED code.

Additional benefits of the dissertation are:

- Create a profile of where LEED New Construction currently stands in the US when compared to the rest of the world.
- Find the relationship between the number of LEED certified personnel inside and outside the US.
- Provide recommendations and sustainable activities that can benefit construction companies.
- Create a quantifiable economic relationship between sustainable and traditional construction when using LEED and the Construction Industry Institute (CII).

The additional benefits are necessary to achieve the overall objective of the dissertation. Currently there is a lack of research related to sustainable construction. The creation of new research related to sustainability is implemented with the goal being awareness and advancement of sustainability in the construction industry.

3.2 Scope

The scope of this dissertation covers the evaluation of the effectiveness of sustainability in relation to construction companies under economic, environmental and social measures. All of the information provided is taken from public and private organizations and does not contain any proprietary information.

3.3 Hypothesis

The hypotheses of this dissertation is to create statements for construction companies that cover the three major components of sustainability: environment, society and economy. How strong is the relationship between sustainable new construction in the US when compared to the rest of the world? The first hypothesis states that if sustainability is implemented in the construction industry in US, the rest of the countries should follow the same trend. What is the relationship between LEED certified people inside and outside the US? The second hypothesis affirms that, upon a visualization test, LEED certification inside the US is creating new influence over people around the world. Lastly, what is the economic relationship between sustainable and traditional construction performed inside a construction company? The third hypothesis affirms that sustainable construction will increase the cost of construction activities when compared to traditional practices.

3.4 Research Framework

The problem statement addresses the need to transform the way buildings are designed and operated to enable a healthier and more socially responsible environment without considerably increasing the costs. Three research questions are defined to form the core of the dissertation to be presented.

3.4.1 Question #1, Environment

How strong is the relationship between sustainable new constructions in the US when compared to the rest of the world? A rigorous analysis through different statistical methods that can probe the relationship between the increase of new construction inside the US compared to other countries under the LEED code. LEED New Construction only includes buildings that are being newly constructed or going through a major renovation. Buildings such as schools, retail, hospitals, data centers, warehouses, distribution centers, and healthcare are included under this category.

The following activities were implemented to address this question:

1. Collection of data from the USGBC. During this step, data will be organized based on the location of the new construction under the LEED code.
2. Input the data into the statistical software. MiniTab 2018 was chosen as a statistical tool. MiniTab 2018 is a statistical analysis program that automates calculations and the creation of graphs, allowing the user to focus more on the analysis of data and the interpretation of results.
3. Organize the data in different columns and rows based on the location of the LEED New Construction.

4. Generate graphic comparison of the LEED New Constructions according to their location.
5. Identify the best places to practice LEED certification as a norm based on the results of number of LEED New Constructions per country.

A rigorous analysis through different statistical methods that can probe the relationship between the increase of new constructions inside the US compared to the rest of the world is implemented.

3.4.2 Question#2, Social

What is the relationship between LEED certified people inside and outside the US? A visualization test using Microsoft Excel Power Maps that can visually emulate the relationship between LEED certified personnel in the US when compared to other countries. The following activities were completed:

1. Collect data from the LEED directory that includes the number of people certified under the LEED code as a LEED AP BD+C (LEED Accredited Professional in Building Design and Construction).
2. Input the data by using Microsoft Power Maps software. Power maps is a visualization tool provided by Microsoft to emulate 3-Dimensional mapping.
3. Create drawings and maps with the extracted data.
4. Generate graphic comparison of the people certified in LEED according to their location per state and country.

Use the method of visualization to show the relationship between people certified in the US and around the globe. The creation of a 3-Dimension simulation is implemented in this process to generate the visualization of the data. This simulation is a contribution that can be used for educational purposes inside the construction industry and for students at The University of Alabama.

3.4.3 Question#3, Economy

What is the economic relationship between sustainable practices and traditional work performed inside a construction company? The analysis will be performed under 41 sustainable actions provided by the Construction Industry Institute (CII) for labor. The purpose of the research is to provide the construction management sector with guidance to determine, implement, and assess effective sustainability solutions during the construction phase of a project. The research makes it easier to understand the construction management decisions that offer opportunities in sustainability and a higher impact on the work site.

The objective is to determine the most effective practices for deploying sustainability focused initiatives during the construction phase of a LEED project. Identify construction decisions that have the potential to enhance sustainability under the LEED code. The following activities were completed to organize the information of the research:

1. Collect data from the CII directory, this data presents common sustainable practices for construction projects. The data includes name of the sustainable technique, description, primary and secondary construction function, economic impact and category of metric. CII is an organization that collects, processes, analyzes, and disseminates essential information to their members. CII offers learning and growth by implementing proven research and advances in the construction industry.

2. Organize the data by using Excel spreadsheets. A LEED related activity is assigned for every sustainable practice in construction, when available.
3. Create an economic analysis for the sustainable practices depending on in-house construction or contract development, when available.
4. Generate graphs of comparison for the analyzed data based on the economic impact of the CII recommendations.
5. Present conclusions and recommendations for future construction work under sustainable practices and the LEED code.

3.5 Data Sources

Data sources were identified, reviewed, and analyzed to provide the necessary information to answer the questions advanced in this dissertation. The data sources used for this project include:

1. *LEED Directory of Constructions and People, accessed by: USGBC organization;* data that includes a directory of people and new constructions certified by LEED. LEED New Construction includes buildings that are new construction or going through a major renovation. LEED people include the personnel certified under BD+C (Building Design and Construction). The data sheets were organized into Excel spreadsheets. The Excel spreadsheets were subdivided into the following categories: name, status, city, state, job title, organization name, year of certification, and LEED certification status.
2. Reports from the Construction Industry Index (CII); the CII established a research team to examine ways of increasing sustainability during construction and develop metrics for measuring improvement in sustainability performance. The CII research team established

41 different actions that project construction teams can take to enhance the overall sustainability of their project.

CHAPTER 4

ENVIRONMENT

Chapter 4 explains the relationship between sustainable new construction in the US compared to the rest of the world. A rigorous analysis through different statistical methods that can probe the relationship between the increase of new green construction inside and outside the US under the LEED code is presented.

4.1 Introduction

The construction industry continues to experience a lack of research related to sustainability for construction companies. Sustainability in construction is generally thought of as a new and innovative topic inside the industry. Buildings have a major role to play in sustainability through their construction, the lifetime of their operation, and patterns of development. As the planets population continues to rise, construction of new buildings expands even faster. Different estimates indicate that two-thirds of the structures that will exist in 2050 will be built between now and 2050 (USA Today, 2010).

The green building portion of the construction market is increasing as follows: 2% for nonresidential construction in 2005, 12% in 2008, and 28-35% in 2010 (Ewing, et al., 2010). The concept of green building provides a vision for resource equity between developing and developed nations. As green building practice guidelines develop, construction moves toward a more responsible use of resources. These improvements enable developing nations to copy and attain improvement in the quality of buildings. Different countries utilize different US standards to build in their region.

4.2 Research Statement

To understand sustainability, an analysis to measure the influence of the LEED code in other countries is performed. The scope of work includes only new construction under LEED. New construction are defined as more than 3-story buildings destined for commercial or residential purposes. For the purpose of this research, LEED New Construction does not include the following: hospitals, renovations, existing buildings, interior designs, neighborhood development, homes, and projects that do not possess a certification level.

Many countries outside the US build buildings using the LEED code. New data is created by finding the relationship between the number of new buildings in the US and other countries under the LEED code. The number of new buildings is measured and compared using statistical analysis and modeling software such as Microsoft Excel and MiniTab 2018. Following the research, results and conclusions are presented that inform the reader on how the LEED code is influencing other countries around the globe.

4.3 Data Collection

Data collection is the process of gathering and measuring information on targeted variables for an established system, this enables the opportunity to answer different questions about a specific focus. While methods can vary by the type of discipline, the goal is to capture quality evidence that allows analysis to lead to the formulation of convincing answers to the questions proposed. During this research, data from the USGBC was collected including the following parameters:

- Project name and address
- Certification level and Certification Date
- Gross Square Foot
- Number of points achieved in the certification

The data was organized as Excel spreadsheets and labeled into cells that will include the current location of the project in order to create the analysis. Based on the location of every LEED New Construction project the following Table 1 was created. Table 1 includes the number of LEED New Construction per year by country.

Table 4.1: Number of LEED New Construction per year

	USA	China	Turkey	Brazil	UAE	Germany	Mexico	Spain	Chile	India	South Korea
2000	2	0	0	0	0	0	0	0	0	0	0
2001	6	0	0	0	0	0	0	0	0	0	0
2002	20	0	0	0	0	0	0	0	0	0	0
2003	42	0	0	0	0	0	0	0	0	1	0
2004	78	0	0	0	0	0	0	0	0	1	0
2005	146	1	0	0	0	0	1	0	0	1	0
2006	210	3	0	0	2	0	0	6	0	3	0
2007	363	0	0	1	1	0	1	0	0	4	0
2008	505	1	0	1	0	0	0	0	0	6	0
2009	1053	12	1	3	1	1	0	0	2	4	1
2010	1491	21	1	4	14	2	5	2	0	1	2
2011	1685	22	8	7	13	11	2	4	3	1	5
2012	1908	34	5	9	15	5	8	3	5	0	9
2013	1821	44	9	14	15	11	8	12	10	0	8
2014	1559	49	21	28	15	15	10	15	14	0	4
2015	1378	51	34	34	17	21	16	13	16	5	12
2016	1213	58	26	27	17	7	17	14	10	12	9
2017	1186	66	33	22	13	21	16	12	7	18	3

Analyzing this information indicates that LEED is present in 150 countries and territories, only the ten most influential countries were picked for this research, because the rest of the countries do not present enough numbers of LEED New Construction. The majority of countries do not present enough LEED New Construction during the time frame of 2000-2017. Therefore, only the top-10 countries with the highest number of LEED New Construction were included in the data analysis section. Additionally, a figure is included in Appendix A that presents a graph with the number of LEED New Construction outside USA. This graph presents the top-10 countries for comparison purposes.

4.4 Data Analysis

Data analysis is the process of inspecting, transforming, and modeling data to discover additional useful information in a project. The process of data analysis refers to breaking a whole into separate components for individual examination. During this process, new data will be obtained and can be converted into useful information for the benefit of the construction industry.

Only quantitative data was used for this analysis. Quantitative data is information that can be measured and written down in numbers. The following steps were developed for the statistical analysis of the relationship between LEED New Constructions inside and outside the US: Johnson Transformation, Linear Regression, and Correlation.

4.4.1 Johnson Transformation

There is a wide range of statistical tests that can be used for data analysis. The decision on which statistical test to use depends on the research design, the distribution of the data, and the type of variable. If the data is normally distributed, the parametric tests should be chosen. If the data is not normally distributed, the non-parametric tests should be chosen. A complete statistical analysis is developed below to find if the data is normally distributed. In case the data is determined to be: "not normally distributed", a non-parametric focus will be interpreted with the information. The non-parametric methods that can be implemented are:

- Wilcoxon rank-sum test, test for difference between two independent variables. It considers magnitude and direction of difference.
- Wilcoxon sign-rank test, test for difference between two related variables. It considers magnitude and direction of difference.
- Sign test, tests if two related variables are different and ignores magnitude of change, it only considers direction.

Normality test is used to determine if a data set is well-modeled by a normal distribution and to compute how likely it is for a random variable underlying the data set to be normally distributed. After running a normality test (Figure 4.1) from Table 1 for the data of USA LEED New Construction in MiniTab 2018, the following information was generated.

Descriptive Statistics

N	N*	Mean	StDev	Median	Minimum	Maximum
18	0	814.778	721.352	779	2	1908

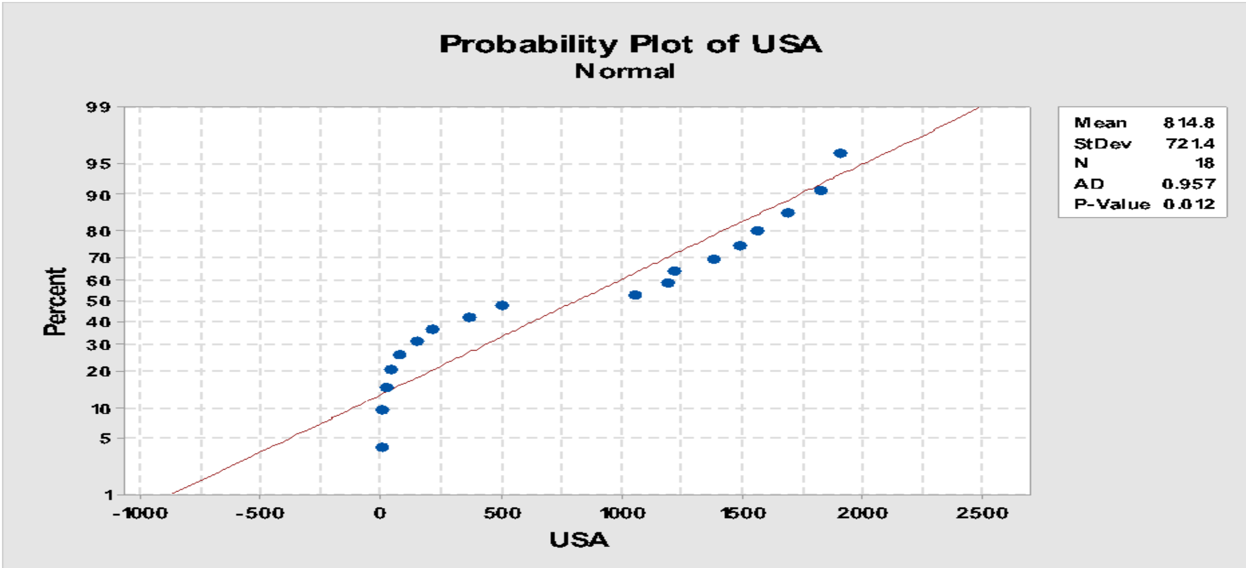


Figure 4.1: Probability Plot of USA- Normality

In descriptive statistic terms, the goodness of fit of a normal model is measured by evaluating the graph. The graph is able to show that the data is normally distributed to a certain extend. If the fit is poor it means the data is not well modeled in the respect of normal distribution. In this case, this assumption cannot be proven. Our example of data does not possess enough information to completely affirm that USA LEED New Construction is normally distributed.

The next step is to run a goodness of fit test through MiniTab 2018 (Table 2). The different types of distribution tests that will be considered are the following: normal, box-cox transformation, lognormal, 3-Parameter Lognormal, Exponential, Weibull, 3-Parameter Weibull, Smallest Extreme Value, Largest Extreme Value, Gamma, 3-Parameter Gamma, Logistic, Loglogistic, 3-Parameter Loglogistic, and Johnson Transformation. These are other commonly used distribution methods that can be used to find how the data is distributed. The graphs for all the types of distribution tests are included in Appendix A.

The Anderson-Darling (AD) value measures how well the data fits a specified distribution. The p-value depends on the value for the AD (Table 2). Small p-values means that the null hypothesis can be rejected. Therefore, the data does not come from the named distribution.

Minitab 2018 displays a normal probability plot and a p-value for the input data. The data shown by the Johnson Transformation chart appears to be normal where the data points follow an approximately straight line and the p-value is 0.908. When several distributions are observed, the one that demonstrates the largest p-value can be assumed as a better match for the data. Consequently, it is assumed that the Johnson transformation follows a normal distribution.

Table 4.2: Goodness of Fit Test

Distribution	AD	p-value
Normal	0.957	0.012
Box-Cox Transformation	0.802	0.030
Lognormal	1.109	<0.005
3-Parameter Lognormal	1.148	0.083
Exponential	2.036	0.007
2-Parameter Exponential	1.059	0.048
Weibull	0.996	<0.010
3-Parameter Weibull	1.023	0.012
Smallest Extreme Value	0.913	0.018
Largest Extreme Value	1.118	<0.010
Gamma	0.876	0.033
3-Parameter Gamma	0.910	0.022
Logistic	0.970	0.006
Loglogistic	1.012	<0.005
3-Parameter Loglogistic	0.980	0.004
Johnson Transformation	0.176	0.908

In the next step, a Johnson Transformation analysis (Figure 4.2) was run to find the transformation function. The following information was found:

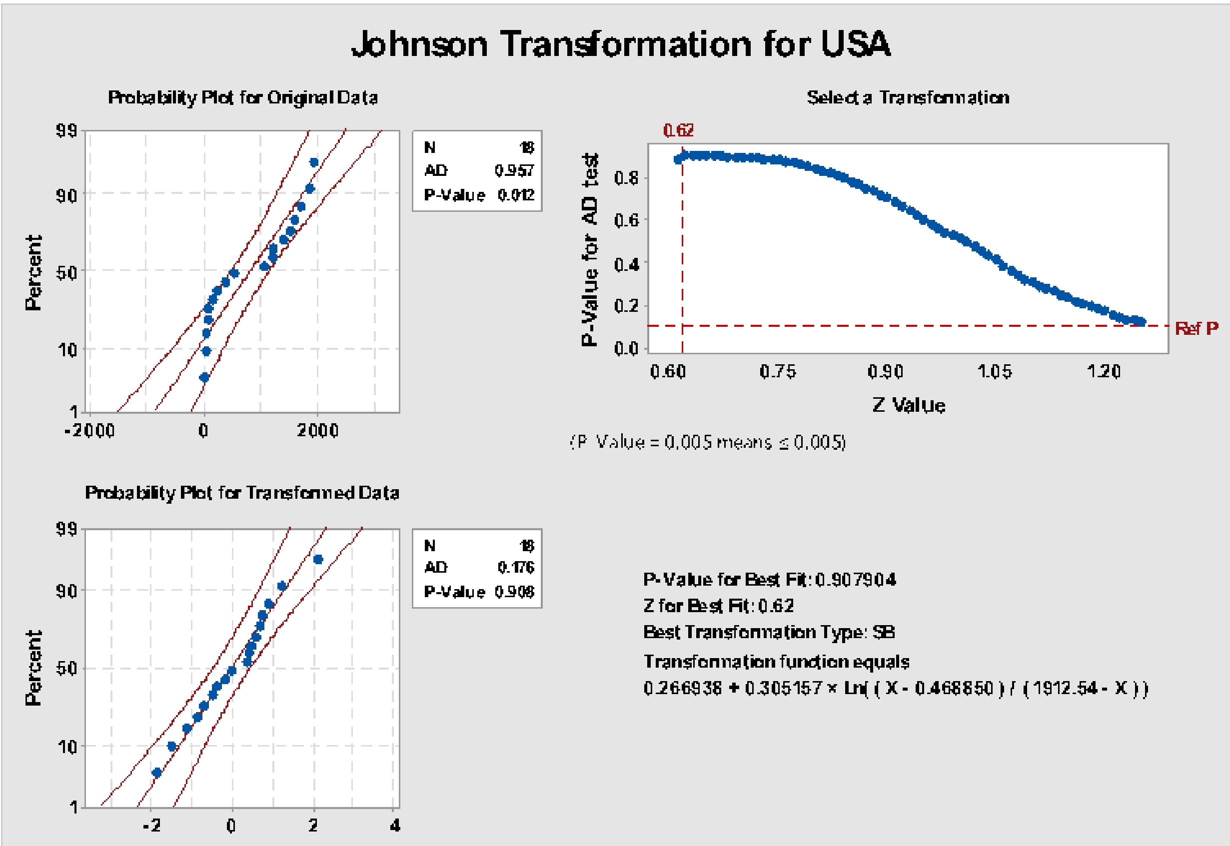


Figure 4.2: Johnson Transformation for USA

MiniTab 2018 displays the parameters of the Johnson transformation function that produces the best fit. The Johnson transformation function for USA LEED New Construction buildings is:

Equation 1

0.266938 + 0.305157 × Ln((X - 0.468850) / (1912.54 - X)), where X = number of buildings.

The Johnson Transformation function is used to transform USA data for LEED New Constructions and minimize the number of missing values in some years. The transformed data is then used to fit a simple linear regression model on the next section.

4.4.2 Linear Regression

Linear regression is a statistical method used to model the relationship between a dependent variable (Y) and independent variables (X) using a forecasting straight line. These relationships are modeled using linear functions whose unknown parameters are estimated using the data provided. Linear regression is represented by the following equation: $Y= a + b^* X +e$. Where 'a' is the intercept, 'b' is the slope of the line, and 'e' is an error term. Linear regression assesses if change in one variable predicts change in another variable. Two different types of regression were used in this work: simple regression and multiple regression. Simple regression can test how change in the forecast variable predicts the level of change in the outcome variable. Multiple regression confirms how change in the combination of two or more forecast variables predict the level of change in the outcome variable. The type of data collected for this step is focused for simple regression, rather than multiple regression. Forecasting, relation between variables, and prediction are expected outcomes in the dissertation. All the parameters provided by the USGBC are quantitative data, using simple linear regression was the best method to predict unchanged parameters.

Using MiniTab 2018, the data was input and the regression equation, model summary, and analysis of variance were found. Using Microsoft Excel, the data is put into a graph and a trend line using a linear forecast can be included for USA and the top 10 countries working with the LEED code.

The Johnson Transformation is used to transform USA data. The transformed data is then used to fit a simple linear regression model. The result is shown in Figure 4.3.

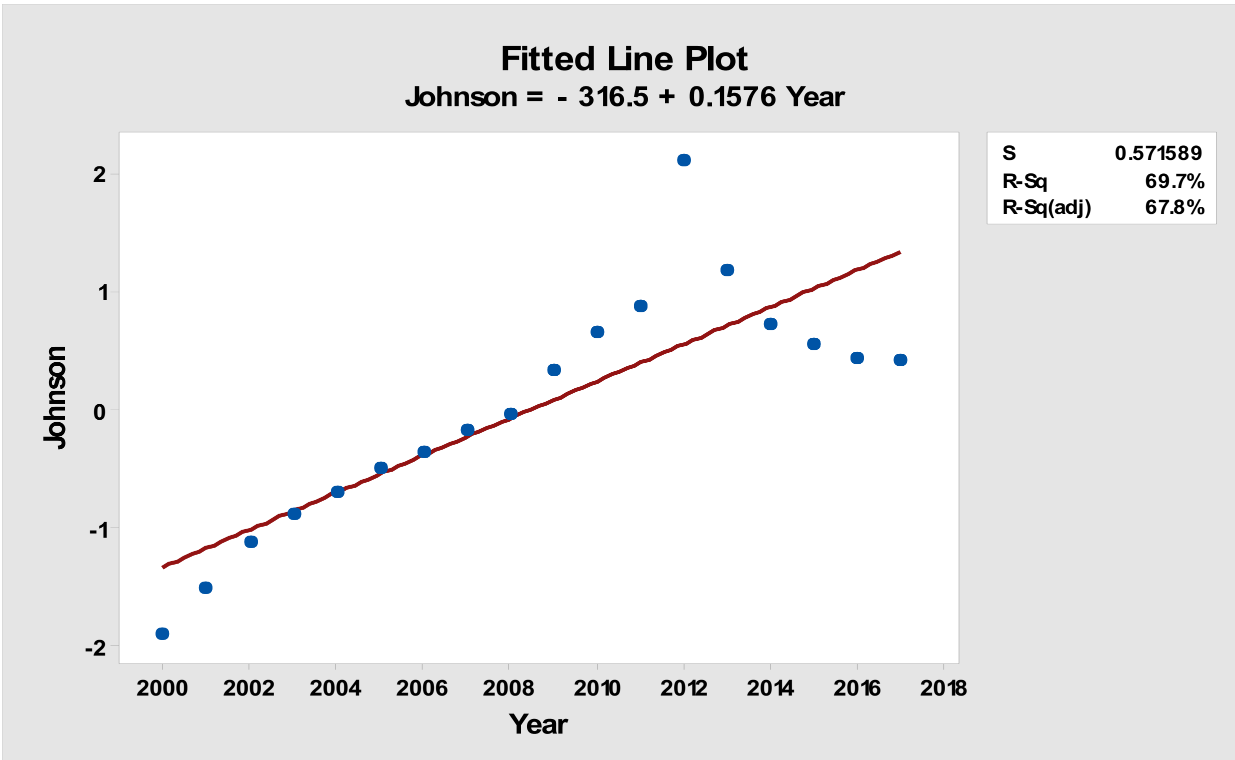


Figure 4.3: Johnson Fitted Line Plot

This linear model can be used to predict future LEED New Construction under the current activities from year 2000-2017 in US. The following equation was created:

Equation 2

Johnson = -316.5 + 0.1576 (X), where X=the year, and Johnson = the number of LEED New Construction.

For the rest of the countries, due to a small sample size (i.e. too many 0 values), a normality test cannot be performed. In this research, the data is assumed to be normal and fit, with simple linear regression models for each country. The results are shown in Appendix B to illustrate the linear regression model of LEED New Construction among the top-10 countries (besides the US) with the highest number of LEED New Constructions.

4.4.3 Correlation

Correlation is also tested to demonstrate if there is any relationship between the improvement of LEED New Construction in the US when compared to other countries. Correlation does not fit a line between data points. The main goal of correlation is to measure how variables change when the other variables do not. Correlation tests look for an association between variables. Three types of correlation analysis were used: pearson correlation, spearman correlation, and chi square. Pearson correlation tests for the strength of the association between two continuous variables. Spearman correlation tests for the strength of the association between two ordinal variables that do not rely on the assumption of a normal distributed data. Chi square tests for the strength of the association between two categorical variables. A correlation coefficient (R) will be computed in order to find the relationship between new buildings under the LEED code from country to country.

Pearson Correlation is the recommended method for the type of data that is being used during this research because there is a linear relationship between the variables. Pearson Correlation is used to calculate the correlation matrix shown in Table 4.3.

Table 4.3: Correlation Matrix for Countries compared to the US

	USA
USA	1.0000
China	0.7806
Turkey	0.5391
Brazil	0.6483
UAE	0.9062
Germany	0.6730
Mexico	0.6499
Spain	0.6300
Chile	0.6781
India	0.1543
South Korea	0.7844

The value inside the matrix is the correlation coefficient (R). The correlation coefficient measures the strength and direction of a linear relationship between one country and the US. The value of R is always between +1 and -1. To interpret (R) value the following brackets were used:

1, perfect positive linear relationship

0.70, strong positive linear relationship

0.50, moderate positive linear relationship

0.30, weak positive linear relationship

0, No linear relationship

4.5 Results and Conclusions

In construction, buildings have the capacity to make a major contribution to the environment. This contribution can be positive or negative, depending on the quality of the construction. Based on this concept the above research tries to make sustainable construction easier to understand, evaluate, and apply. The results of the research provide a test on where is sustainability positioned inside the construction industry. The following results and conclusions were found in the research:

- Looking at the different data and graphs through linear regression, visually there is not enough information from foreign countries for the years 2000-2017 to be able to predict a trend for the future. The data is not normally distributed, therefore, the prediction of future values in foreign countries is not possible using the normality test.
- Analyzing the results of the correlation test, the United Arab Emirates, South Korea, and China were found to have a strong positive linear relationship with the US. A positive linear relationship demonstrates that when the US is building LEED New Construction, these three countries tend to increase their LEED New Construction, as well. The three countries also possess close commercial ties and mutual economic agreements with the US.
- There is not enough information in the last 17 years to assume a defined trend for the LEED New Construction internationally. The data outside US is considered not normally distributed.
- After a normality test, it was found that the data for US LEED New Construction is normally distributed. The test that best accommodates the type of data being used is the Johnson Transformation. MiniTab 2018 displays the parameters of the Johnson

transformation function that produces the best fit. The Johnson transformation function for USA LEED New Construction buildings is: Equation 1.This function is introduced into a regression analysis (fitted line plot) to predict future values. The Johnson transformation is used to predict future LEED New Construction under the current activities from year 2000-2017 in the US. Equation 2 was created as a contribution to predict the number of LEED New Construction buildings inside US for future years.

- Many international locations have access to on-site LEED training courses. Everything that needs to be learned is included in the exam preparation material provided by the USGBC through online access. The LEED exams are administered internationally by official testing centers, such as Prometric. All the exams are computer-based and most countries/territories with LEED presence, possess a test center designated to administer the exams.

CHAPTER 5

SOCIETY

Chapter 5 describes the relationship between LEED certified people in the US and the rest of the world. A data visualization test, using power maps, demonstrates how LEED certified personnel inside and outside the United States is distributed. A virtual model is created in Microsoft Excel for visual data analysis in 3-Dimensions (3-D).

5.1 Introduction

LEED is a framework for identifying and implementing design, construction, operations, and maintenance for neighborhoods and buildings. Currently, LEED is a voluntary tool that serves as a guideline for sustainability rating. LEED rating systems address commercial, institutional, and residential building developments. LEED for New Construction and Major Renovations was developed for the commercial building industry and has been updated several times to address the different needs of market sectors. Different credentials are awarded by LEED to people that are interested in learning and implementing sustainable concepts into their construction projects and major renovations (Cato, 2009).

LEED credentials denote proficiency in sustainable design, construction, and project management. Currently, there are more than 200,000 professionals working directly with the LEED code. People pursue LEED credentials because of the demand for green jobs, to increase their own knowledge, and to join a network of elite professionals in sustainability. The credentials process was developed to encourage professionals to maintain and advance their expertise in sustainability.

Data related to sustainability is hard to find and very limited (Bluebeam, 2009). The data provided by the USGBC is not well organized and needs better visuals in order to understand sustainability for the coming years. Utilizing tools such as power maps, is a great form to visually demonstrate how LEED personnel are distributed.

5.2 Data Visualization

Data visualization is a field of study that strives to accurately communicate data visually. Data visualization utilizes statistical graphics and information to communicate data more effectively. Effective visualization helps to improve the analysis of data. Data visualization is viewed as a branch of descriptive statistics. The increased amount of data or "big data" in recent years, have led to new software for statistical analysis. Big data is data sets that are so large and complex that traditional data-processing application software are not adequate to perform a correct analysis. Big data challenges include capturing the data, data storage, data analysis, sharing, transfer, visualization, querying, updating, and data source.

Data is growing faster every year because technology is continually expanding and evolving. New devices have larger storage capacity as time goes by and also, new are being replace by newer devices. Consequently, the price of data storage is becoming more affordable. The world's technological per-capita capacity to store information has doubled every 40 months since the 1980s (Hilbert and Lopez, 2011). The global data volume will grow exponentially from 44 zettabytes (seventh power of 1000) between 2013 and 2020 (Makrufa, 2017). By 2025, it is expected there will be 163 zettabytes of data (Reinsel et al., 2017). Database management systems will generally encounter difficulties while analyzing big data. Data visualization is a response to this type of data and is considered a tool designed for the future.

5.3 LEED Credential

A LEED credential is a seal of quality that assures employers, coworkers, and clients a level of competence in green designs. There are three levels a person can pursue in the LEED Professional Credentialing program:

- LEED Green Associate: Denotes basic knowledge of green design, construction and maintenance. This is the first certification that assures that the person understands the concepts of working with green construction. LEED Green Associate certification requires an individual to pass a 100-question exam that is completed in less than 2 hours. The content of the exam focuses on integrated design, core sustainability concepts, green building technology, and other aspects of the LEED rating system. No working experience is required to be accredited as a LEED Green Associate.
- LEED AP (Accredited Professional) with specialty: LEED AP involves an advanced depth of green building practices and it reflects the ability to implement green design concepts in construction projects. Similar to the green associate examination, a 100-question examination must be passed before accreditation. The LEED AP examination is chosen from different specialties that include the following: LEED AP Building Design + Construction, LEED AP Homes, LEED AP Interior Design + Construction, LEED AP Neighborhood Development, and LEED AP Operations + Maintenance. LEED AP certification requires the LEED Green Associate examination and is highly advised to

possess extensive work experience in green construction or design before pursuing the LEED AP certification.

- LEED Fellow: People with this accreditation are a highly accomplished class of individuals with a minimum of 10 or more years of experience in professional green building. LEED Fellows need to be nominated by their peers and possess a LEED AP with specialty credential.

The only credential analyzed in this research is LEED AP: BD+C (Accredited Professional: Building Design and Construction) because this credential embodies the major components of construction and design. LEED AP BD+C is also the accreditation with the highest number of participants after LEED Green Associate. LEED Green Associate does not require work experience, but LEED AP BD+C is highly encouraged to possess green work experience.

5.4 Research Statement

Following an investigation through the USGBC, big data was collected with a spreadsheet that includes more than 35,000 columns of names, addresses, locations, and LEED accreditation of the people with a LEED AP BD+C credential.

The research provides a visualization test of the number of people that are accredited through LEED AP BD+C and how they are distributed across the US and the rest of the continents. During the visualization test a tool called Power Maps from Microsoft Excel was implemented. The main regions where LEED accredited personnel are located are shown through different views and 3-Dimensional modeling (3-D). A visualization test is a more practical alternative to analyze big data such as, the database from USGBC. Additionally, a 3-

dimensional simulation was created for educational purposes on the number of LEED AP BD+C accredited personnel around the globe.

5.5 Data Collection

The following activities were completed during the research:

1. Collect qualitative data from the LEED directory that includes the number of people working in green construction through LEED. The data includes member employees, chapter members, USGBC faculty, USGBC staff, USGBC students, LEED Fellows, Experts, and LEED Professionals. Today, the USGBC serves as the main representation of green building in the US. The USGBC collects, processes, analyzes, and disseminates essential statistical data to the public.
2. Organize the data by using Excel spreadsheets. LEED AP BD+C will be the variable of observation.
3. Input data into Power Maps from Microsoft Excel.
4. Create drawings, maps, and movies with the extracted data as data visualization.
5. Generate visual comparison between the number of LEED AP BD+C by their city location per state in US.
6. Generate graphic comparisons between the number of LEED AP BD+C by their city location in Europe, South America, Australia, Asia, and Africa.

Use data visualization tests to create 3-dimensional simulations on the number of LEED AP BD+C people distributed around the globe.

5.6 Data Analysis

Working with power maps enables the visualization of big data in a more organized and detailed manner. The following figures show the visualization test of the number of LEED AP BD+C in the US when using 2-Dimensions (flat map) and 3-Dimensions (Power Map). Figure 5.1 presents the traditional form to visualize a map. It is more difficult to notice how many people are certified by LEED in each state. This map does not show the quantity of LEED personnel unless the user positions the cursor on top of every state. Figure 5.2(a) and (b) are the 3-Dimensions (3-D) maps created for this dissertation. The new map provides an easier form to visualize the number of LEED certified personnel by using the height of the columns.

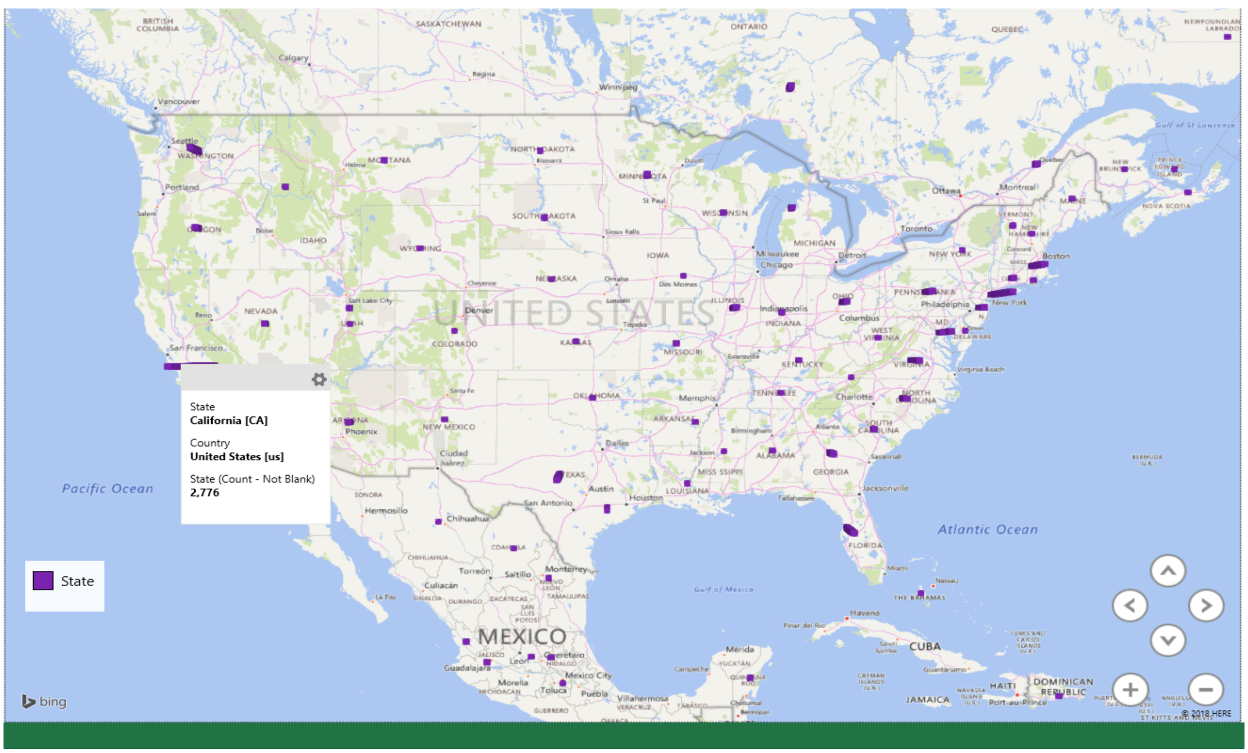


Figure 5.1: 2D Flat Map of the number of LEED AP BD+C by state in US

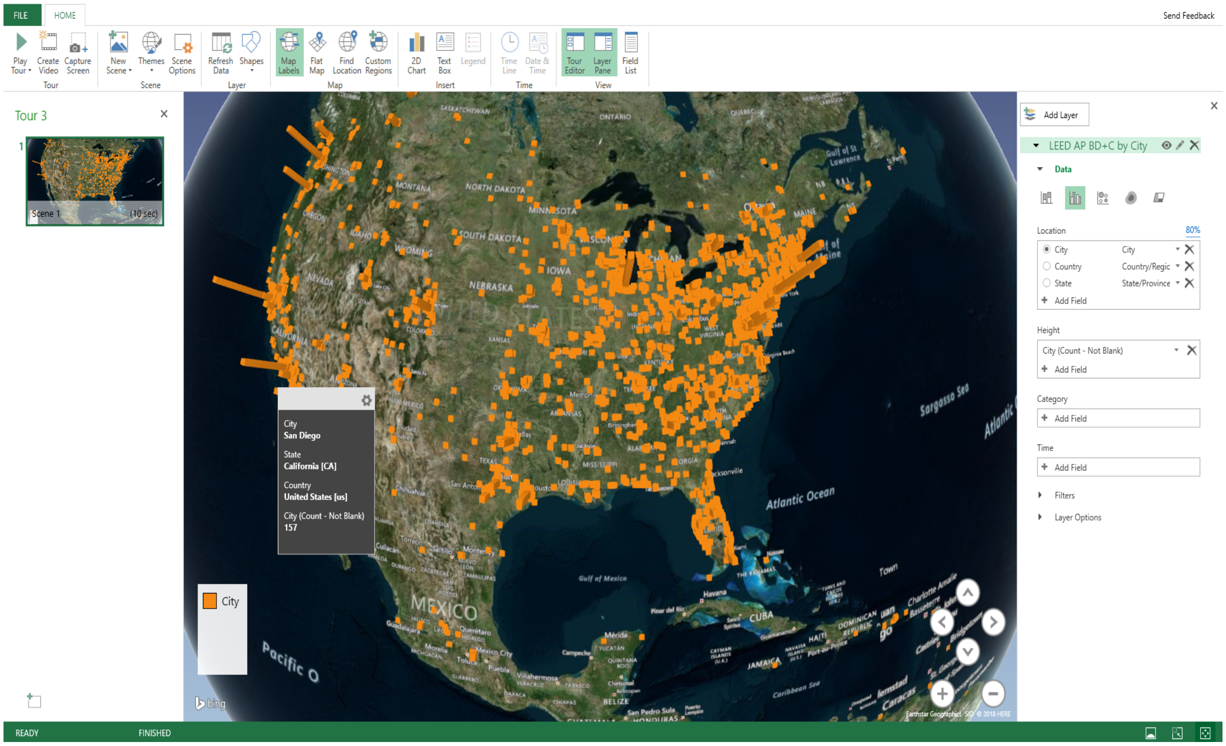


Figure 5.2 (a): 3D Power Map of the Number of LEED AP BD+C by city in US

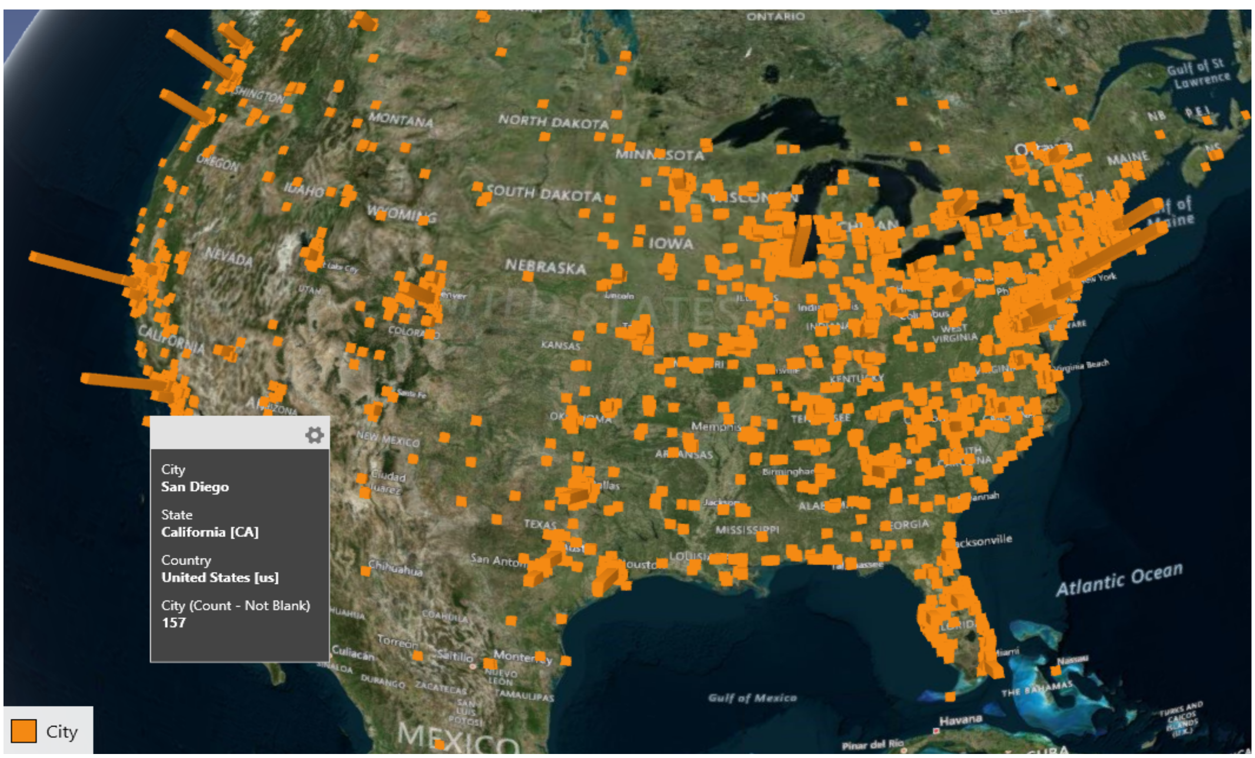


Figure 5.2 (b): Zoom in to the 3D Power Map of the Number of LEED AP BD+C by city in US

Using the data provided by the USGBC, a 3-D model was created to locate all the personnel certified under LEED BD+C around the globe. A simulation was also created to visualize the personnel positioning around the different continents for the dissertation presentation. All the Power Maps with the rest of the continents (Europe, Asia, Africa, South America, Australia) are included in Appendix C. These maps provide the visualization of the number of LEED BD+C personnel in every region.

5.7 Results and Conclusions

The results of this research aspect provide information on where sustainability is positioned inside the construction industry based on the number of LEED AP BD+C personnel. The following results and conclusions were found during this research:

- Data visualization is viewed as a branch of descriptive statistics. The increased amount of data or “big data” in recent years, have led to new software for statistical analysis. Microsoft Excel Power Maps is a practical tool to display big data sets that are larger and more complex than data used with traditional data-processing applications. Traditional data-processing software is not adequate to perform an analysis when using big data.
- A data visualization test was performed to create a 3-dimensional simulation on the number of LEED AP BD+C distributed around the globe. This model can be used for teaching purposes at educational centers and universities.
- 2-D maps cannot create the level of detail that a 3-D simulation can display when working with big data analysis.

- The 3-D Power Map of the number of LEED AP BD+C by city in US, displays a higher level of precision. Using power maps, the zones or regions were the highest number of LEED AP BD+C are concentrated can be displayed for the reader.
- LEED AP BD+C has a presence in every continent, but it is still considered as an emerging market. Cities such as Dubai, Montreal, Hong Kong, Seoul, and Beijing possess the highest numbers of LEED AP BD+C outside the US.
- The states with the highest number of LEED AP BD+C are located in: California (2773), New York (1540), Texas (1304), Illinois (977), and Florida (972).
- The countries with the highest number of LEED AP BD+C, besides the US, are located in: China (2000), Canada (1075), South Korea (412), UAE (322), India (224), United Kingdom (171), Mexico (147), Qatar (145), Egypt (136), Saudi Arabia (133), and Italy (125).

This research includes findings that can be used by the construction industry to improve green construction and be aware of LEED emerging markets.

CHAPTER 6

ECONOMY

Chapter 6 presents an analysis performed under 41 sustainable actions provided by the Construction Industry Institute (CII) of labor in relation to the LEED code. The research presents quantifiable economic relationships between sustainable practices and traditional work inside a construction firm. Additional benefits and construction recommendations will also be included in this chapter.

6.1 Introduction

There has been a lack of research in sustainable techniques used during the construction phase of projects. In response to this need, the Construction Industry Index (CII) solicited a team of researchers to work together in finding different recommendations for sustainability techniques during the construction of a project. The team developed metrics for measuring improvement in sustainability performance. This team assessed sustainable construction techniques with the goal of presenting the benefits to contractors. In this dissertation research, the actions found by the CCI team are correlated to the LEED code to find additional benefits and recommendations for construction companies (CII RT283, 2013).

The economic relationship between sustainable strategies and traditional work completed inside a construction company under the LEED code is analyzed. The analysis is performed under 41 sustainable actions with respect to the impact on labor. The type of labor will include in-house work and contract elements for construction, when available. Additional benefits such as the impact produced over the LEED code and construction recommendations will also be included.

6.2 Research Statement

The purpose of this section of research is to provide the construction management sector with guidance to determine, implement, and assess effective sustainability solutions during the construction phase of a project. The research makes it easier to understand the construction management decisions that offer opportunities in sustainability and a higher impact on the work site. This research focuses on several structured approaches for implementing sustainability to construction service decisions and activities.

The objective is to create a comparison of the most effective practices for deploying sustainability focused initiatives during the construction of a LEED project and identify construction decisions that have the potential to enhance sustainability under the LEED code.

The scope of work is limited to actions that can be implemented by a construction company during a project. The research includes actions that can be performed by a construction manager to ease the application of the LEED code. In addition, actions that affect safety, global projects, and regulatory compliance were excluded from this scope of work.

6.3 Data Collection

The following activities were completed to organize the information and facilitate a case study analysis:

1. Collect qualitative data from the CII directory, this data presents common sustainable practices for construction projects. The data includes name of the sustainable technique,

description, primary and secondary construction function, economic impact and category of metric. CII is an organization that collects, processes, analyzes, and disseminates essential information to their members. CII offers learning and growth by implementing proven research and advances in the construction industry.

2. Organize the data by using Excel spreadsheets. When available, a LEED related activity is assigned for the CII identified sustainable practices in construction.
3. Create an economic analysis for the sustainable practices depending on in-house employee or subcontract expertise.
4. Generate graphs of comparison for the analyzed data based on the economic impact of the CII recommendations.
5. Present conclusions and recommendations for construction firms interested in working under sustainable practices and the LEED code.

6.4 Data Analysis

A case study is performed for the following 41 sustainable actions provided by the Construction Industry Institute (CII) for labor. The CII provides the description of the activity, construction function, economic impact magnitude, and category of metric. During the research, a specific activity is assigned to every CII description. This activity is related to the work proposed by the CII description and is located into one of the four different categories of the construction process. For this research, the construction process is subdivided into the following categories: front-end planning, design, construction, operations & maintenance. After analyzing the activity, a LEED credit is associated for each activity. Additionally, the sustainable process of the activity is compared to the traditional process of the same activity. At the end, different conclusions and recommendations are collected based on the case study.

The cost variation between sustainable and traditional practices is subdivided into the following categories:

- Reduction of Cost: This applies when the sustainable recommendation produces a reduction of cost when compared to the sustainable practice.
- No Additional Cost: The total balance is zero when the sustainable practice is compared to the traditional practice.
- Minimal Additional Cost: When implementing the sustainable practice produces expenses of less than $2,500 per year. The cost of less than $2,500/year is where, according to the research, the majority of the sustainable practices are positioned.
- High Additional Cost: Presents a sustainable practice that possess more than $2,500/year expenses in order to be implemented.

Several CII sustainable actions are related or similar to each other. To a certain extent, some of these actions overlap one over the other. For a better organization of the work proposed, the most representative examples are included below. The complete guide of the 41 CII sustainable actions is included in Appendix D. The following sustainable actions were collected from the CII for the purpose of the case study:

1. Leadership Team Staffing for Sustainable Projects

Description: Employ administrative staff that possess skills and experience in the management of sustainable projects. Identify lacking knowledge inside the company and be prepared to offer training on projects with a focus on environment/community impacts, worker safety cultures, and effective project communication (Azada, 2013).

Construction Function: Project Management

Economic Impact Magnitude: 2

Category of Metric: Benchmarking

****

Activity: Employ a LEED Accredited Professional (AP) certified worker inside the company

LEED Credit: Innovation Credit, LEED AP

Sustainable Practice: According to PayScale forum, median wage for Civil Engineers in 2017 is $74,637/year. LEED AP Exam I and II combined: $550 (USGBC) in-house. $74,637 + $550 = $75, 187.

According to PayScale forum, a Civil Engineer LEED AP salary in 2017 is $84,115/year.

Regular Practice: According to PayScale forum, median wage for Civil Engineers salary in 2017 is $74,637/year.

Analysis: $75,187 / $74,637 = 1.007 < 1.1 (in-house possess minimal additional cost)

$84,115/ $74,637 = 1.12 < 1.1 (above 10% cost)

Ratio < variation of 10%, ok. Minimal additional cost

Construction Stage: Front-End Planning

2. Sustainability Risk Management

Description: Ensure that sustainability risks are incorporated into the project risk management process by addressing environmental, social, and economic threats. Perform a sustainability risk assessment to identify sources and root causes of accidents, releases or spills of hazardous material. Mitigation measures should be developed and employed to minimize negative sustainability impacts (Yilmaz, 2010).

Construction Function: Project Management

Economic Impact Magnitude: 3

Category of Metric: Benchmarking

****

Activity: Perform a sustainability risk assessment

LEED Credit: Sustainable Site Credit, Site Assessment

Sustainable Practice: This activity helps ensure that all LEED credits, that are expected, can be achieved. According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. A sustainability risk assessment should not take more than a few hours for a Civil Engineer to develop. For this case study, CII allocated 4 hours for a Civil Engineer to perform a sustainability risk assessment (CTDOT, 2009).

$40.70 x 4hours = $162.80/month

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Design

3. Sustainability Change Proposal Clause

Description: Consider incorporating a Sustainability Change Proposal clause in the contract, similar to the Value Engineering Change Proposal clauses typically used. Consider giving the contractor the economic savings, leaving the environmental and social/community benefits to the owner (Mandelbaum, 2006).

Construction Function: Contracting

Economic Impact Magnitude: N/A

Category of Metric: Contracting and Procurement, Environmental Footprint

****

Activity: Sustainability Change Proposal Clause

LEED Credit: N/A

Sustainable Practice: Attorney needs to review the new sustainable clause for each project. Lawyer is not part of the construction company in the CII case study. According to the US Bureau of Labor Statistics the average wage of an attorney is $118,160 per year. Every new project will include a different sustainability clause. Therefore, the implementation of this action possesses high additional cost.

Regular Practice: No further action

Construction Stage: Front-End Planning

4. Sustainable Large-scale Earthwork and Grading Operations

Description: Employ a balanced earthwork strategy that minimizes the transportation/placement of excavated soils at offsite locations. Thoroughly evaluate cut and fill requirements to determine the most suitable mix of resources/work sequence and identify opportunities to reuse excavated soils. Consider further improving grading operations by utilizing GPS technologies in lieu of conventional staking methods, to perform soil volume checks, reduce rework, and improve overall operational efficiency (Kourmpanis, 2008).

Construction Function: Field Engineering, Materials Management

Economic Impact Magnitude: 3

Category of Metric: Construction & Demolition Waste

****

Activity: Utilizing sustainable strategies for earthwork such as GPS

LEED Credit: N/A

Sustainable Practice: According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. For this case study, CII allocated 4 hours for a Civil Engineer to develop a sustainable strategy of earthwork (Han, 2006):

$40.70 x 4hours = $162.80/month

No considerable changes in labor, $16.75/hr for earthwork operator using a GPS.

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No considerable changes in labor, $16.75/hr for earthwork operator.

Construction Stage: Construction

5. Indoor Air Quality Improvements

Description: Enhance the indoor air quality of both permanent and temporary facilities by avoiding contamination of HVAC systems, controlling pollutant sources, and interrupting contamination pathways, all during construction. Protect stored or installed absorptive materials from moisture damage. Avoid using permanently installed air handlers for temporary heating/cooling during construction (Joshi, 2009).

Construction Function: Sites facilities and Operations

Economic Impact Magnitude: N/A

Category of Metric: Facility Commissioning, Environmental Footprint

****

Activity: Building flush-out and test air contaminant levels

LEED Credit: Indoor Environmental Quality Credit, Indoor Air Quality Assessment

Sustainable Practice: On average, additional $35 per vent (work performed by a subcontractor)

Regular Practice: Building flush out not required

Analysis: Additional expense of $35/vent (average home $300-$500). Therefore, the implementation of this action possesses minimal additional cost.

Construction Stage: Construction

6. Sustainability Lessons Learned

Description: Review sustainability performance as part of the post-implementation evaluation report. Consider holding a meeting with key stakeholders to identify sustainability successes, evaluate opportunities for improvements, and collect lessons learned for enhancing the sustainability of future projects. Consider this activity an opportunity for benchmarking the project's sustainability performance (Gormley, 2011).

Construction Function: Quality Management, Commissioning, & Handover

Economic Impact Magnitude: N/A

Category of Metric: N/A

****

Activity: Collection of lessons learned for future projects.

LEED Credit: LEED Recommendation

Sustainable Practice: Collection of lessons learned for future projects can be accomplish by 1 day (8 hours) of workshop per project for the engineer in charge. For this case study, CII allocated 8 hours for a Civil Engineer for a 1day workshop (Adams, 2006).

$40.70 x 8hours = $325.60/project

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No requirements.

Construction Stage: Operations and Maintenance

6.5 Results and Conclusions

The research was conducted to gain a better understanding of the construction management decisions and actions that can offer the maximum opportunity for sustainability impact on a project. Following the research, a better understanding of the effects of these strategies is accomplished. A foundation is set for future decision-making when working for a construction firm. Sustainability techniques are learned and compared with the LEED code. The research suggests that higher levels of effort are necessary for sustainability to be effective during the construction of projects.

The Construction Industry Index (CII) identified 41 sustainable actions that project teams can apply during construction to enhance the sustainability of a project. The research was able to identify a cost variation between sustainable and regular practices and also, the moment or phase these sustainable practices can be applied during the project. Additionally, a comparison between the CII sustainable actions and the LEED code is presented. The research demonstrates the relationship between CII practices and the LEED code. The following conclusions were generated during the research:

- A project can be divided into the following stages: front-end planning, design, construction, and operation & maintenance. Front-end planning possesses 8 CII sustainable practices. The design stage comes with 6, construction stage with 19, and operation & maintenance with 9 CII sustainable practices. Figure 33 identifies the moment when CII sustainable practices can be applied during the project. Therefore, it is concluded that during the process of a project, CII emphasizes the effects of sustainability during the construction stage.

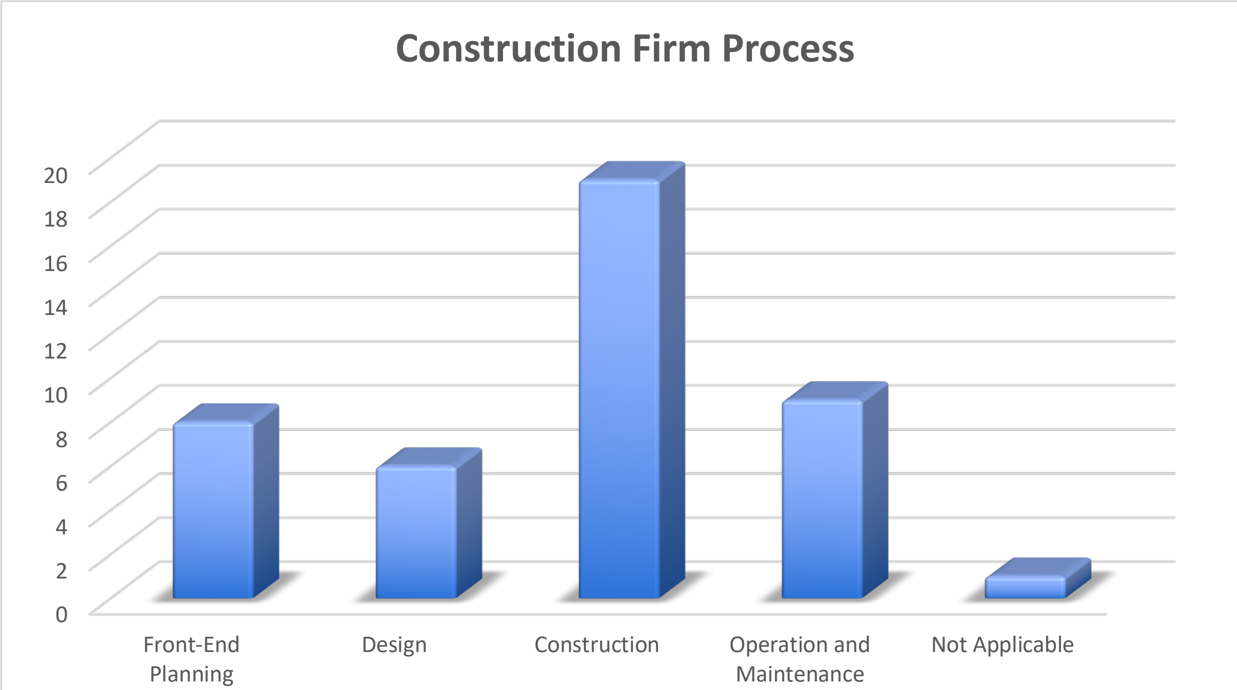


Figure 6.1: Process of a Project inside a Construction Firm

- It is concluded that 22% of CII sustainable practices do not contribute to any LEED credit from the case study. Plus, an extra 20% of CII sustainable practices can be used as a LEED recommendation to try to accomplish LEED credits, but have no direct effect in accomplishing credits by itself. Figure 6.2 presents the percentages that the CII sustainable practices influence to accomplish a LEED credit by category.

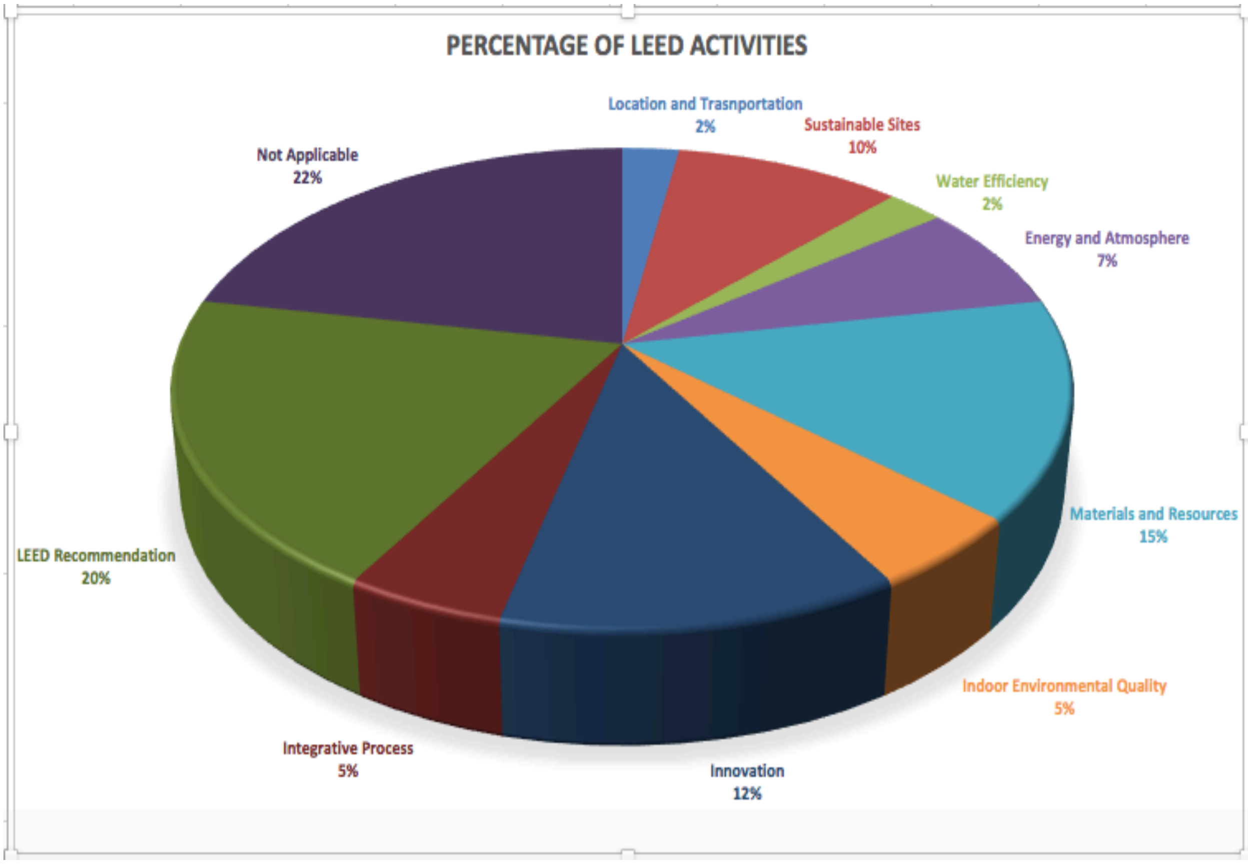


Figure 6.2: CII Sustainable Practice Percentages for LEED credits

- There are 11 CII practices that do not require additional expenses in labor to be implemented for sustainability when compared with traditional construction during the case study. A minimal additional cost (less than $2,500 per year) is associated to accomplish 21 of the sustainable practices proposed by the CII. Only 3 practices require high additional cost (>$2,5000 per year) to accomplish sustainability.
- Three of the sustainable practices produce immediate reduction of cost when compared to traditional practices under this case study. It will decrease overhead costs for the construction company.

- Implement a sustainability rewards program inside the construction firm, distributing meeting materials electronically, arranging meetings by telephone or internet to reduce travel, implementing an energy consumption awareness program, and tight quantity estimation can all help reduce construction costs in a firm. Additional profit can be collected by the construction company in case these practices are implemented.

Figure 6.3 shows the cost variation when implementing the CII Sustainable Practices in a project. The cost variation between sustainable and traditional practices is shown in Figure 6.3.

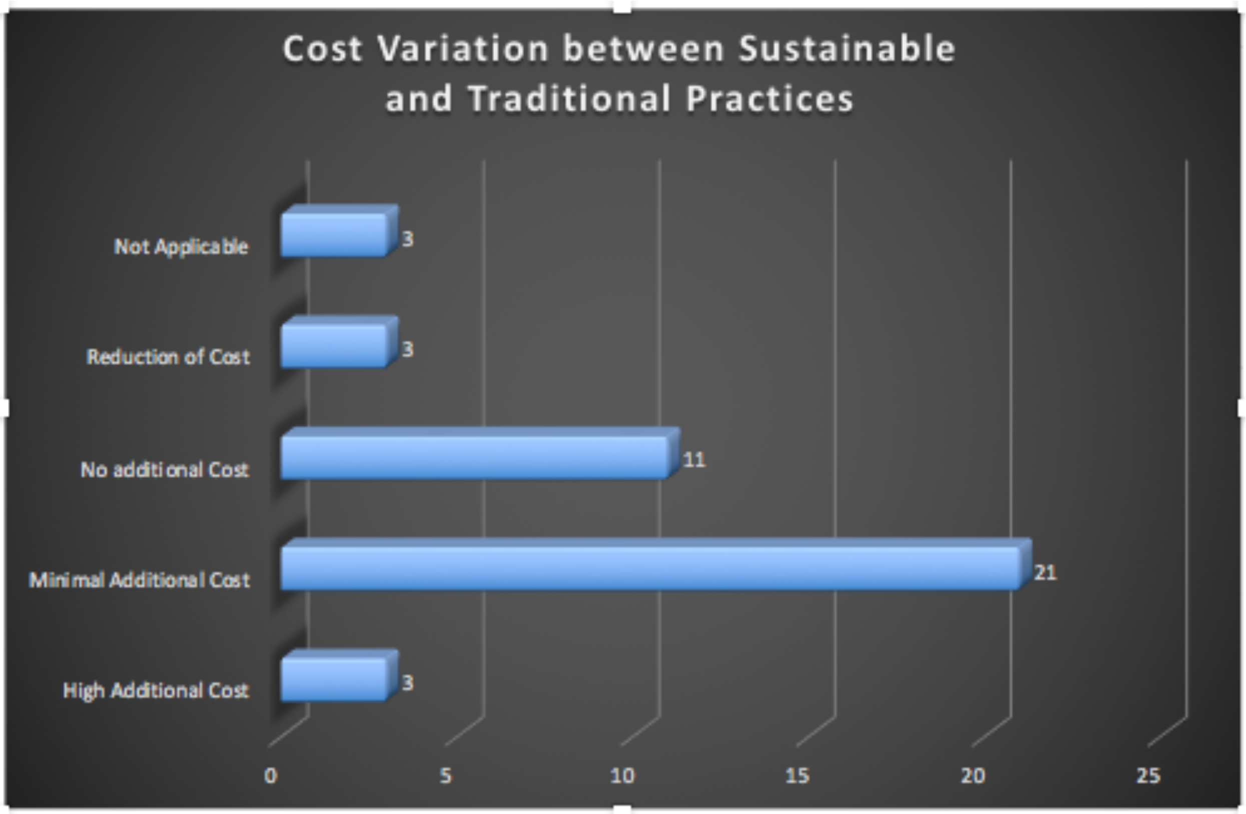


Figure 6.3: Cost Variation between CII Practices

CHAPTER 7

FINAL CONCLUSIONS AND RECOMMENDATIONS

Conclusions of the dissertation are organized in this chapter, this includes the impact that sustainability may have over the environment, society and economy. Summaries of the findings as well as limitations of the research, future research extensions, and new opportunities are also discussed.

7.1 Concluding Remarks

The concluding remarks are structured to address the research statement and the hypothesis of the dissertation. Based on the objectives of the dissertation and the hypotheses initially generated, the conclusions of the research are summarized as follows:

- The first part of the hypothesis includes the following statement, if sustainability is implemented in the construction industry then there is an increase of construction activity in the US tied to the rest of the world. This part of the hypothesis was proven wrong for most of the countries because after applying linear regression analysis, it was demonstrated that the countries with the highest numbers of LEED New Construction are not affected or related to the increase or decrease of LEED New Construction in the US. Looking at the different graphs through linear regression, there is no relation between the trends that occur in one country to another. Every country has different government policies, views on sustainability, and modes of operation. The events that occur in the US do not affect the number LEED New Construction projects internationally. The hypothesis was also proven correct for some countries. After analyzing the results of the correlation test, the United Arab Emirates, South Korea, and China were found to have a strong positive linear relationship with the US. A positive linear relationship demonstrates that when the US is building LEED New Construction, these three countries tend to increase their LEED New Construction, as well. The three countries also possess close commercial ties and mutual economic agreements with the US.

- The second part of the hypothesis states that there is a relationship between people certified on LEED inside and outside US, which is correct. Following a visual analysis performed through power maps using the 3-D model, it is observed that people certified under LEED BD+C are present in every continent. The majority of licensed LEED BD+C are located in the US, but LEED BD+C personnel are also present in 104 other countries and territories.

  The third part of the hypothesis includes the following, construction companies are not interested in using sustainable practices because it increases the expense of their projects. This was proven wrong because many construction firms encourage their personnel to pursue a career on LEED. Adding sustainable construction to a company's capabilities can create a market advantage for the construction firm and increase the percentage of financial success. A growing demand of green projects present an opportunity to generate additional revenues for construction firms. If green construction is one of the capabilities inside a firm, this can diversify the mode of generating business. Following the research on the case study from the CII, it was also proven that the majority of sustainable practices do not require additional expenses in labor to be implemented for sustainability when compared with traditional construction. The downside of the sustainable focus lies with the additional fees associated to achieve any level of certification on LEED. The LEED code includes additional fees for registration and certification along with commissioning fees that can increase the budget for a construction project.

- Data visualization is considered as a branch of descriptive statistics. The increased amount of data in recent years, have led to new software techniques for statistical analysis. Microsoft Excel Power Maps is a very practical tool to display “big data” sets that are larger and more complex than traditional data-processing applications. Traditional data-processing software will not be adequate to perform a correct analysis when using big data.
- A profile that locates where LEED New Construction currently stands in the US, when compared to the rest of the world, was created for the purpose of the dissertation.
- Following a normality test, it was found that the data for US LEED New Construction is normally distributed. The test that best accommodates the type of data being used is the Johnson Transformation. MiniTab 2018 displays the parameters of the Johnson transformation function that produced the best fit. The Johnson transformation function for USA LEED New Construction buildings is: Equation 1.

  This function is introduced into a regression analysis (fitted line plot) to predict future values. The Johnson transformation is used to predict future LEED New Construction under the current activities from year 2000-2017 in the US. The following equation was created: Equation 2.
- Currently there is a lack of research related to sustainable construction. The analysis of data related to sustainability is implemented during the dissertation to keep the construction industry improving.

- It is concluded that 22% of CII sustainable practices do not contribute to any LEED credit during the case study. Plus, an extra 20% of CII sustainable practices can be used as a LEED recommendation to try to accomplish LEED credits, but have no direct effect in accomplishing LEED credits by itself.
- Three of the recommendations under, “Reduction of Cost” will positively affect the overhead costs of the construction company if they implement the recommendations provided by the CII. Therefore, these actions should result in extra savings for the construction firm.
- The construction industry is affected by the economic trend. Most of construction companies need to adjust to fluctuations in the economy. The economy plays an important role in the overall health of the construction industry. A strong economy, where employment rates are high and consumer spending is up, helps boost many types of businesses. An economic downturn will create less business for construction suppliers. Therefore, driving the prices of equipment higher and forcing construction companies to pay more for supplies. When the economy is weak, the requirements of loan approvals are also stricter. This could lead to unfinished construction projects and foreclosures. Additionally, political instability or presidential election can influence people not to invest. Consequently, this will affect the construction industry, such as the US 2012 elections.

The main objective of this dissertation is to evaluate the effectiveness of sustainability, for the construction industry to assist the environment, society, and the economy through the LEED code. The above remarks are stated to fulfill the main objective of the dissertation.

7.2 Contributions and Impacts

Several contributions are identified during this dissertation. These contributions can help supplement and enhance existing information in both academic level and inside the construction industry concerning the application of the LEED code. The following statements are the specific contributions of this dissertation:

- A data visualization test was performed to create a 3-dimensional simulation on the number of LEED AP BD+C distributed around the globe. This model can be used for teaching purposes at educational centers and universities.
- Identify different sustainable measures provided by the CII that improve the sustainable focus without creating additional expenses for the construction industry. These sustainable measures include the following: implement a sustainability rewards program inside the construction firm, distributing meeting materials electronically, arranging meetings by telephone or internet to reduce travel, implementing an energy consumption awareness program, and tight quantity estimation that can help reduce construction costs inside a firm.
- The construction industry lacks access to measurable data. The dissertation identifies the effect of LEED certification in construction and provides recommendations and research for construction companies to improve their sustainable focus.

The impact generated by the dissertation will positively affect the sustainable construction environment because it will contribute to the current knowledge available to construction firms. This type of research will also encourage future generations to take care of the environment and continually improve sustainable construction techniques.

7.3 Future Research

Progress has been made relating sustainability in construction, but many research questions and technical issues still remain. Based on the dissertation findings, the following activities are recommended to further this body of knowledge:

- Continue additional in-depth analysis of each sustainable practice recommended by the CII. Additional research should be implemented by field trials to provide further implementation guidance.
- Develop methods for overcoming the implementation barriers associated with each sustainable practice depending on the region. Some sustainable practices are not applicable if the project is located outside the US.
- Develop a school educational program to enhance construction industry awareness related to construction sustainability.
- Conduct sustainable practice applications through more CII research. Additional sustainable practices can be included for study.

The above recommendations, if acted upon would provide answers to the many questions related to sustainability in construction. Sustainable construction is a topic that is new and original and requires accessible and reliable data to properly understand the costs and benefits.

REFERENCES

Adams, W.M. (2006). *The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century.* IUCN the World Conservation Union, pages 543-551.

Agyekum, K., Ayarkwa, J. (2013). Mimizing Materials Wastage in Construction: A Lean Construction Approach. *Journal of Engineering and Applied Science,* 5(1), pages 125-146.

Ayoko, O.B. (2007). Communication openness, conflict events and reaction to conflict in culturally diverse workgroups. *Cross Cultural Management: An International Journal,* 14(2), pages 105-124.

Azada, J., Rochte, M. (2013). *Workforce for Good: Employee Engagement in CSR and Sustainability*. Workforce for Good, pages 1-22.

Azevedo, I. L., Morgan, M.G. (2012). Marginal Emissions Factors for the U.S. Electricity System. *Environmental Science & Technology,* pages 442-448.

Berkemeyer, M.L., Robbins, L. (2008). *Sustainable Design and construction in Industrial Construction.* Construction Industry Institute, pages 1-18.

Bennick, C. (2011). Recycling your bottom line; Reprocessed materials save resources, boost margins, and cut costs. *Sustainable Construction Magazine,* pages 1-19.

Bennick, C. (2012). Contractors Fuel Savings with Biodiesel. *Sustainable Construction Magazine,* pages 18-22.

Bluebeam (2009, August). Paperless Project Produced with PDF Revu. *Building Design and Construction,* 50(8), pages 1-13.

Boeing, C., (2014). "LEED-ND and Livability Revisited": *Berkeley Planning Journal*. Volume 27 Issue 1, pages 31-55.

Cato, M.S. (2009). *Green Economics: An Introduction to Theory, Policy, and Practice.* London: Earthscan.

CEEQUAL. (2008). *CEEQUAL Scheme Description and Assessment Process Handbook*. The Civil Engineering Environmental Quality Assessment and Awards Scheme, pages 1-114.

Chasey, A.D., Agrawal, N. (2012). A Case Study on the Social Aspect of Sustainability in Construction. Presented at the 2012 International Conference on Sustainable Design and Construction, Texas: American Society of Civil Engineers, pages 543-551.

Chester, M. V., Horvath, A. (2009). Environmental Assessment of Passenger Transportation Should Include Infrastructure and Supply Chains. *IOPScience, Environmental Research Letter 4, pages* 1-8.

CII RT 283. (2013). *Industrial Modularization: Five Solutions Element* (Implementation Resource No. 283-2) Austin TX: Construction Industry Institute, pages 1-113.

CTDOT. (2009). *Value engineering Program.* Connecticut Department of Transportation Bureau of Engineering and Construction – Office of Quality Assurance, pages 1-18.

Darling, J. R. (2011). Effective conflict management: use of the behavioral style model. *Leadership & Organization Development Journal,* pages 230-242.

Davies, P.J., Emmitt, S., Firth, S.K. (2013). On-site energy management challenges and opportunities: a contractor's perspective. *Building Research & Information,* pages 450-468.

Diesendorf, M. (2000). Chapter 2- Sustainability and Sustainable Development. In Sustainability: *The Corporate Challenge of the 21st Century* (2nd Ed.), pages 19-27.

Edminster, A. (2010). "Energy Free Homes for a Small Planet": *Green Building Press*, pages 60-68.

Ewing, R., Bartholomew, S. Winkleman, J., Chen, D. (2008). "Growing Cooler: The Evidence on Urban Development and Climate Change". *Washington, DC: Urban Land Institute*, pages 8-20.

FECCA (2011). Harmony in the Workplace – Delivering the Diversity Dividend. *FECCA – Resources.* Retrieved January 15, 2016, from http://www.fecca.org.au/resources/harmony-in-the-workplace-factsheets.

Fuertes, G., Schiavon, S. (2015). "The Role of Plug and Loads in LEED Certification": *Plug Load Energy Analysis*. Volume: 76 pages 328-335.

Gifford, H. (2010). "Gifford Fuel Savings Inc. vs. U.S. Green Building Council" *Journal of the American Planning Association,* Volume 77 Issue 47, pages 33-37.

Gormley, J.H. (2011). Construction Contracts for sustainable Projects. *Sustainable Construction Magazine,* (Spring 2011), pages 1-12.

Hageman, K. (2013). Let There Be Light – Light Tower Lamp Options: What Sustainable Contractors Should Know. *Sustainable Construction Magazine,* (Spring 2013), pages 21-33.

Han, S., Lee, S. (2006). Simulation analysis of productivity variation by global positioning systems (GPS) implementation in earthmoving operations. *Canadian Journal of civil Engineering, 33,* pages 1105-1114.

Hanna, A.S., Chang, C., Lackney, J.A. (2008). Impact of shift work on labor productivity for labor intensive contractor. *Journal of Construction Engineering and Management, 134(3),* pages 197-204.

Harper, D., (2017). "Sustainability": *Online Etymology Dictionary* http://www.dictionary.com/browse/sustainability (Accessed: 03/20/2017)

Hilbert, M., López, P. (2011). "The World's Technological Capacity to Store, Communicate, and Compute Information”. *Science Harvard Journal*, pages 60–65.

Jassawalla, A., Truglia, C., Garvey, J. (2004). Cross-cultural conflict and expatriate manager adjustment: An exploratory study. *Management Decision,* pages 95-120.

Joshi, S. (2009). “Product Environmental Life-Cycle Assessment Using Input-Output Techniques.” *Journal of Industrial Ecology,* pages 95-120.

Kats, G., Alevantis, L., Berman, A., Mills, E., Perlman, J., (2003). “The Costs and Financial Benefits of Green Buildings” *Report to California's Sustainable Building Task Force.* http://www.calrecycle.ca.gov/GreenBuilding/Design/CostBenefit/Report.pdf (Accessed: 3/26/2017)

Kibert, C.J. (2010). “Sustainable Construction – Green Building Design and Delivery.” *Green Building Press*, pages 22-44.

Kourmpanis, B., Papadopoulos, A., Moustakas, K., Stylianou, M., Haralambous, K.J., Loizidou, M. (2008). Preliminary Study for Management of Construction and Demolition Waste. *Waste Management and Research 2008, 26(3),* pages 267-275.

Leech, G. (2012). Greening Warfare? Lockheed Martin’s sustainability agenda. *Canadian Dimension,* 46(4), pages 25-27.

LEED (2009). “LEED® Green Building Rating System for New Construction & Major Renovations.” *Version 3 USGBC*: pages 10-72. (Retrieved: 11/26/2016)

Lindley, S. (2012). Exploring Regional Futures, Tools and Methodologies. *Regional Environmental Change,* 2(4), pages 163-176.

Lowe, Watts, Jack, Norman (2011). "An Evaluation of A BREEAM Case Study Project": *Sheffield Hallam University Built Environment Research Transaction,* pages: 42–53.

Makrufa, H. (2017). “About Big Data Measurement Methodologies and Indicators”. *International Journal of Modern Education and Computer Science,* pages 1-9.

Mandelbaum, J., Reed, D.L. (2006). *Value Engineering Change Proposals in Supplies or Services Contracts,* pages. 1-36.

Navon, R., Maor, D. (2010). Equipment replacement and optimal size of a civil engineering fleet. *Construction Management and Economics,* 13(2), pages114-183.

Newsham, G., Mancini, S., and Birt, B. (2009). “Do LEED-certified buildings save energy? Yes, but… “*: Energy and Buildings*. Volume 41 Issue 8: pages 897–905.

Raulerson, J., (2012). "Phipps Production Greenhouse Attains LEED Platinum": *Journal of the American Planning Association,* Volume 55 Issue 12, pages: 27-42.

Reinsel, D., Gantz, J., Rydning, J. (2017). "Data Age 2025: The Evolution of Data to Life-Critical". *International Data Corporation*, pages 1-25.

Retzlaff, R., (2008). "Green Building Assessment Systems: A Framework and Comparison for Planners." *Journal of the American Planning Association*, Volume:74 Issue 4, pages 505-519.

Schiavon, S., Altomonte, S. (2013). “Occupant satisfaction in LEED and non-LEED certified buildings”: *Buildings and Environment*. Volume 68 Issue 12: pages 66–76.

UN Documents (2012). “Our Common Future”: *Report of the World Commission on Environment and Development* http://www.un-documents.net/ocf-02.htm (Accessed: 1/15/2017)

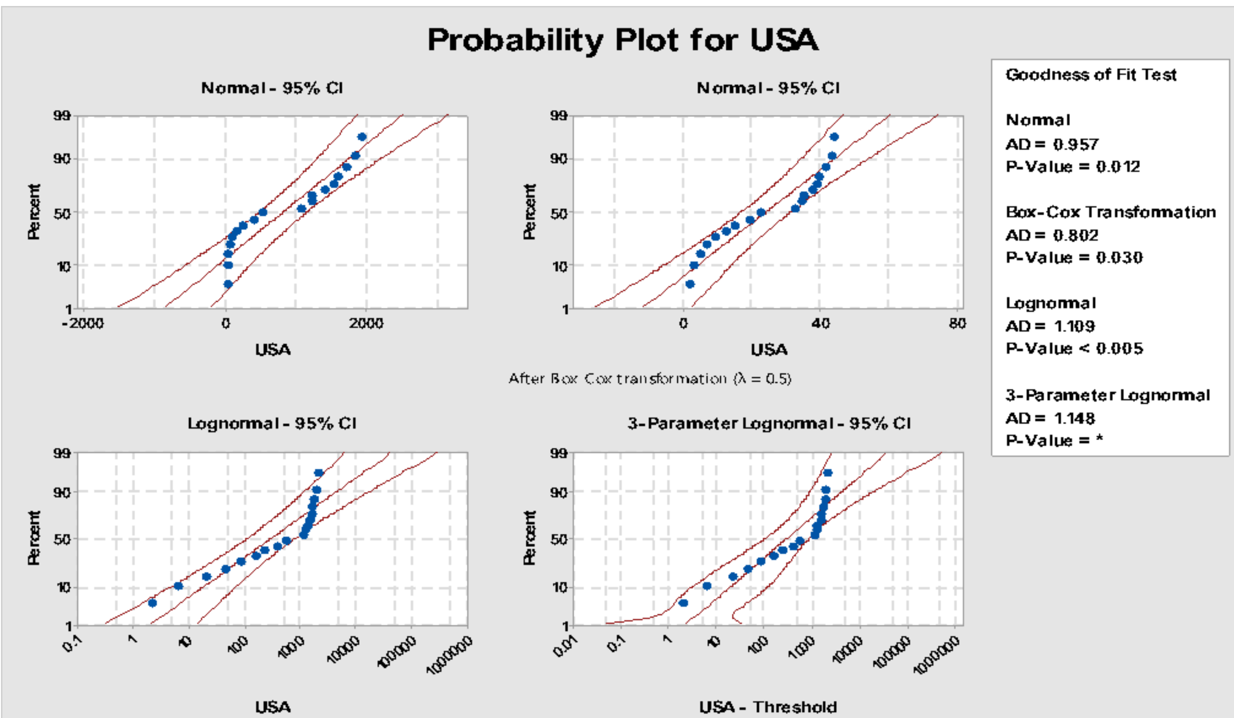
USA TODAY (2010), “In U.S. building industry, is it too easy to be green?” http://www.usatoday.com/story/news/nation/2012/10/24/green-building-leed-certification/1650517/ (Accessed: 02/02/2017)

Yilmaz, A.K., Flouris, T. (2010). Managing corporate sustainability: Risk management process-based perspective. *African Journal of Business Management,* pages 162-171.

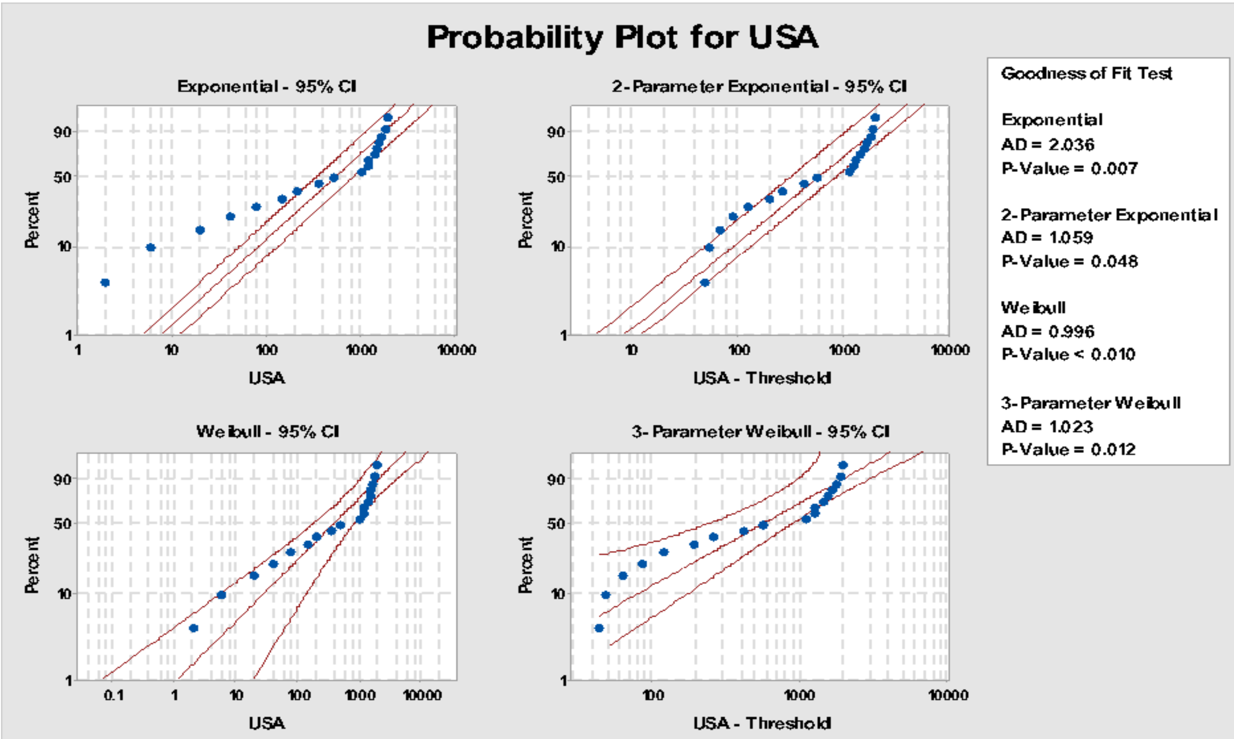
APPENDIX

A. Graphs for the types of distribution tests considered for the normality analysis on LEED New Construction inside the US.

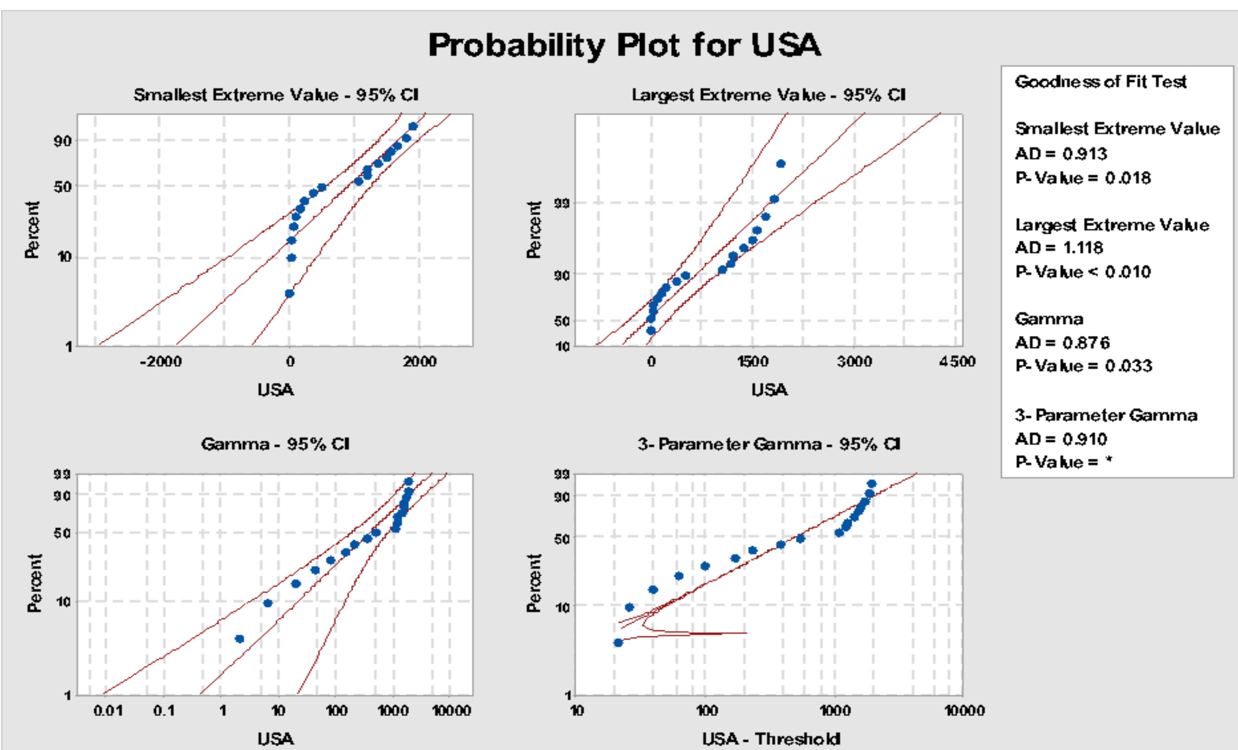
A.1: Probability Plot of USA Test 1



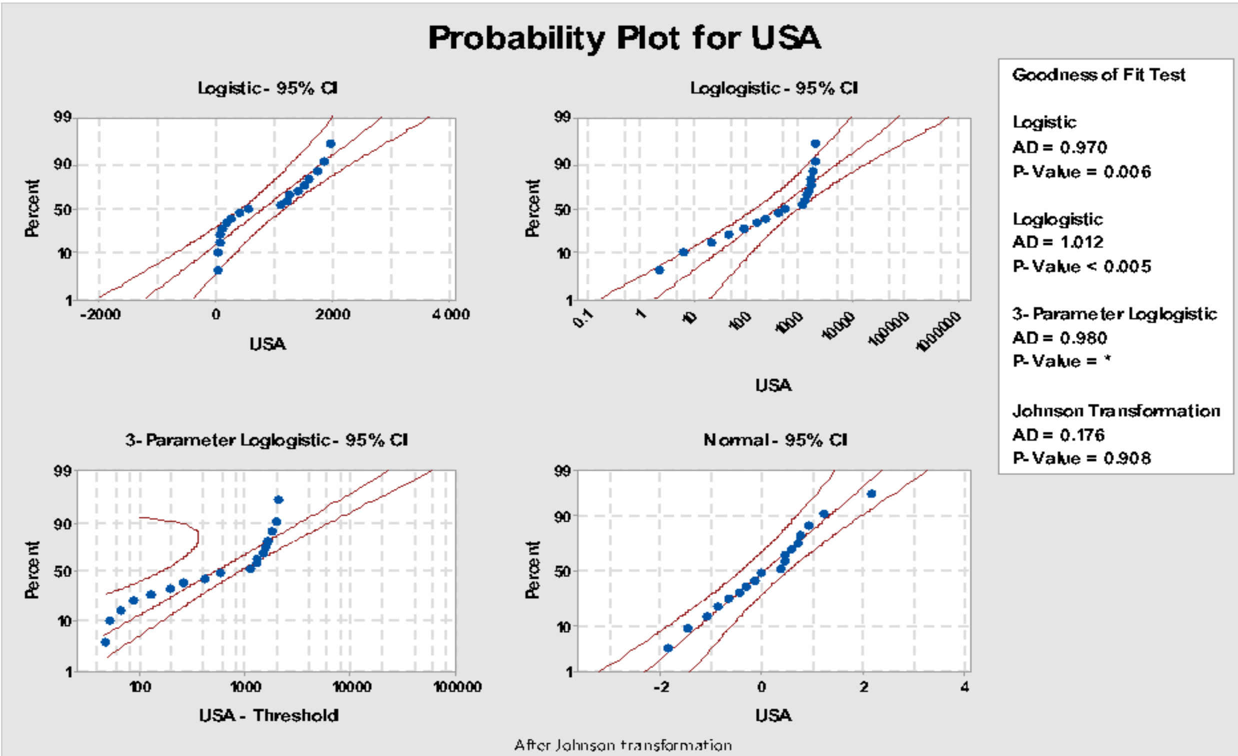
A.2: Probability Plot of USA Test 2



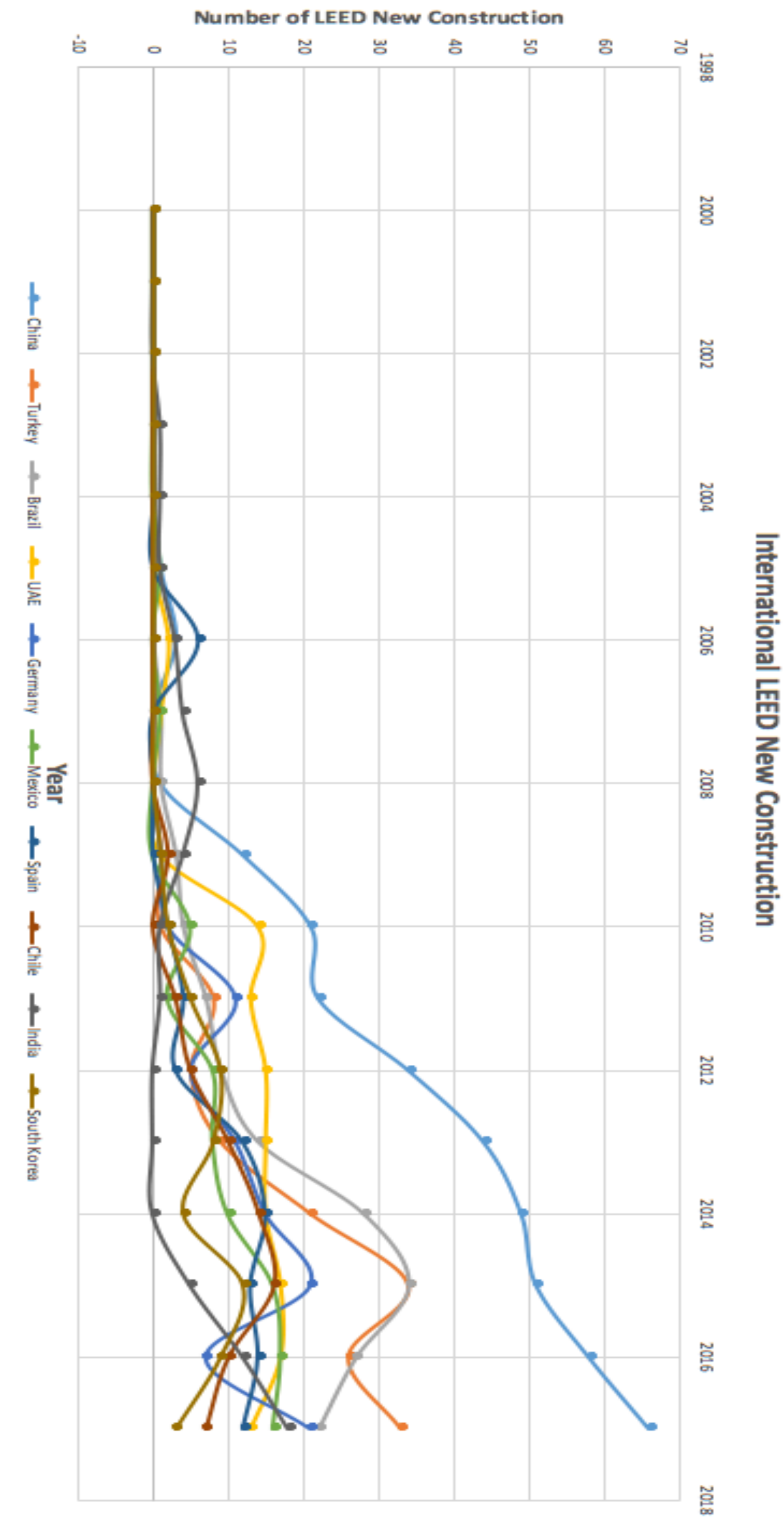
A.3: Probability Plot of USA Test 3



A.4: Probability Plot of USA Test 4

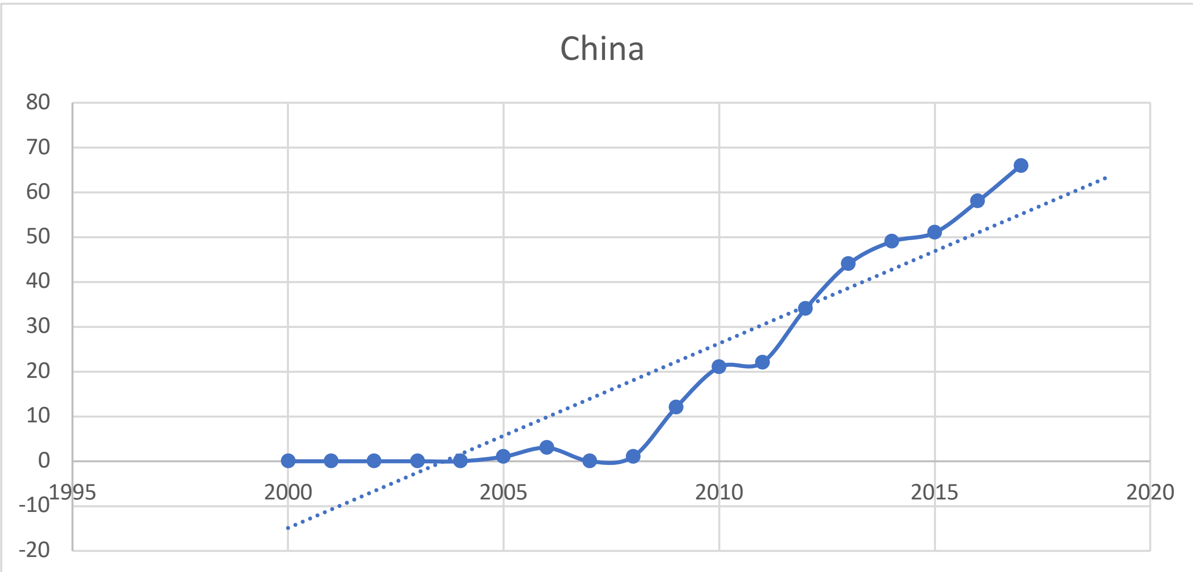


A-5: International LEED New Construction

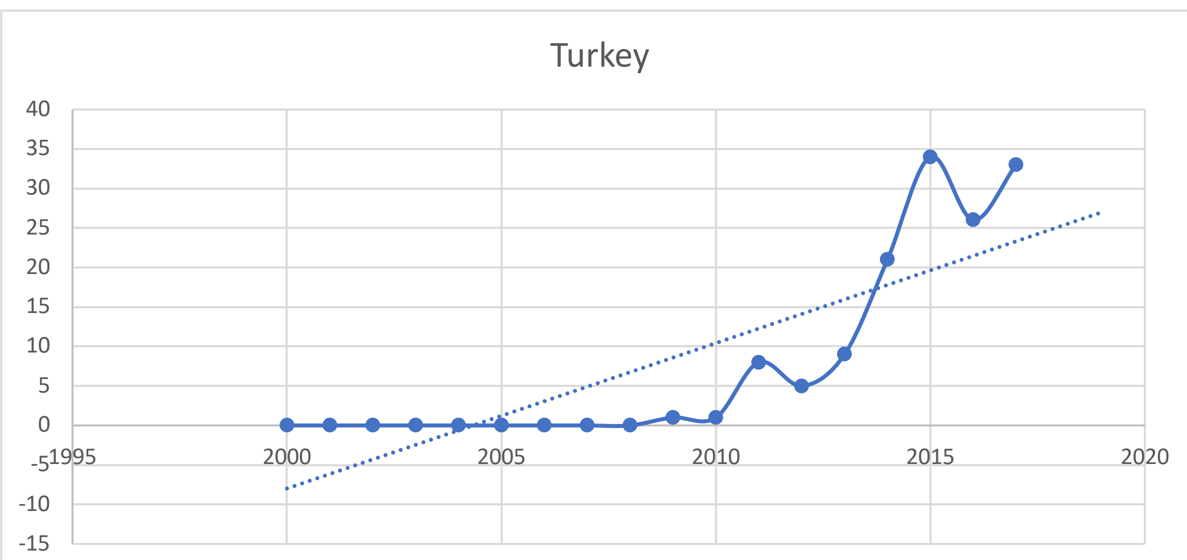


B. Linear regression model of LEED New Construction among the top-10 countries (besides the US) with the highest number of LEED New Constructions.

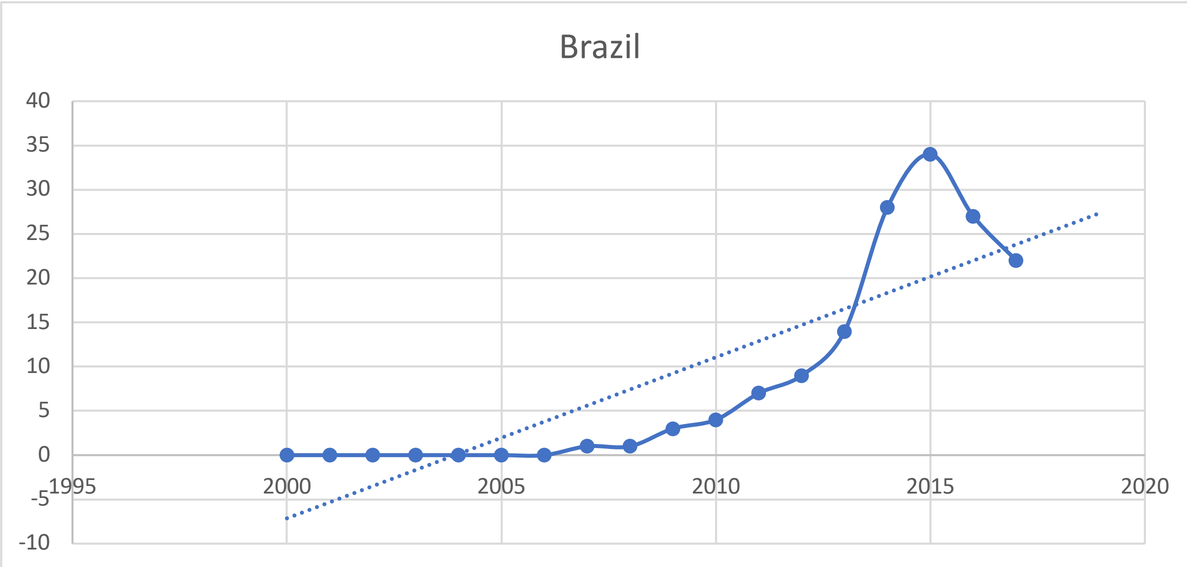
B.1: Linear Regression for China



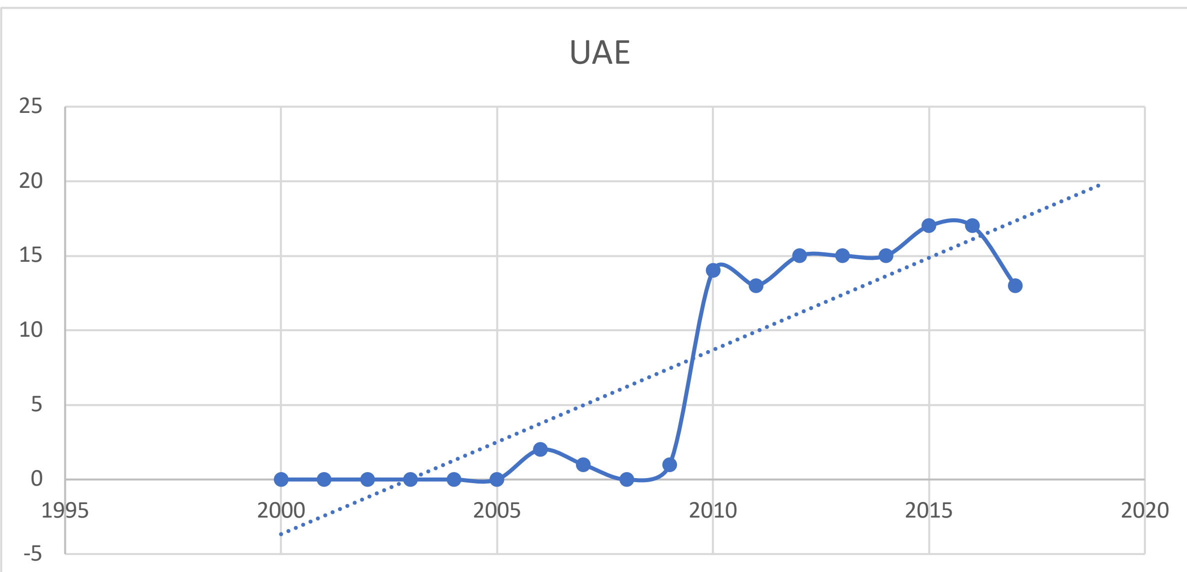
B.2: Linear Regression for Turkey



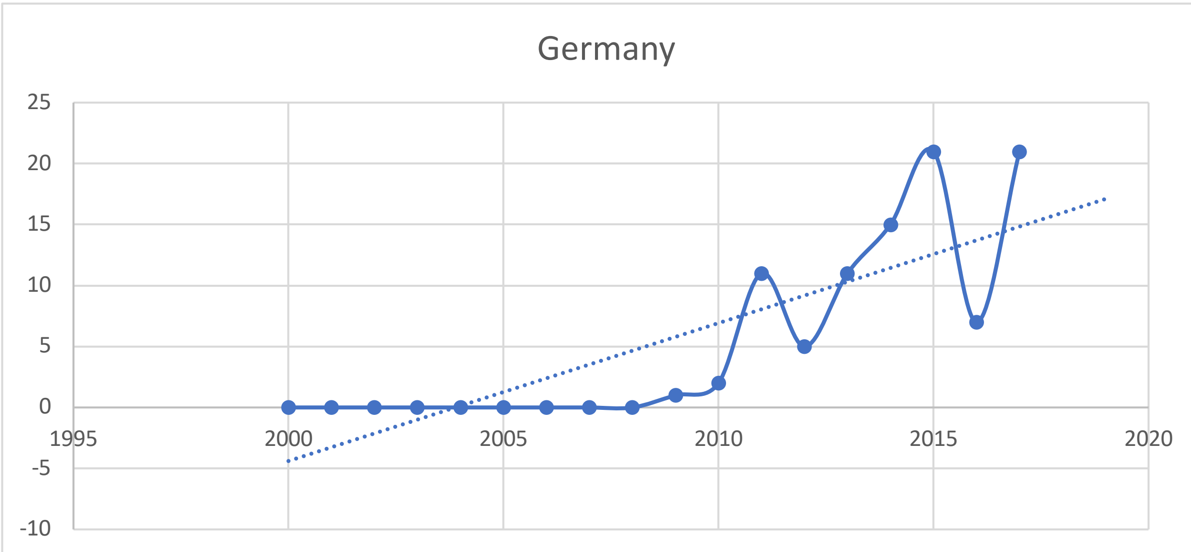
B.3: Linear Regression for Brazil



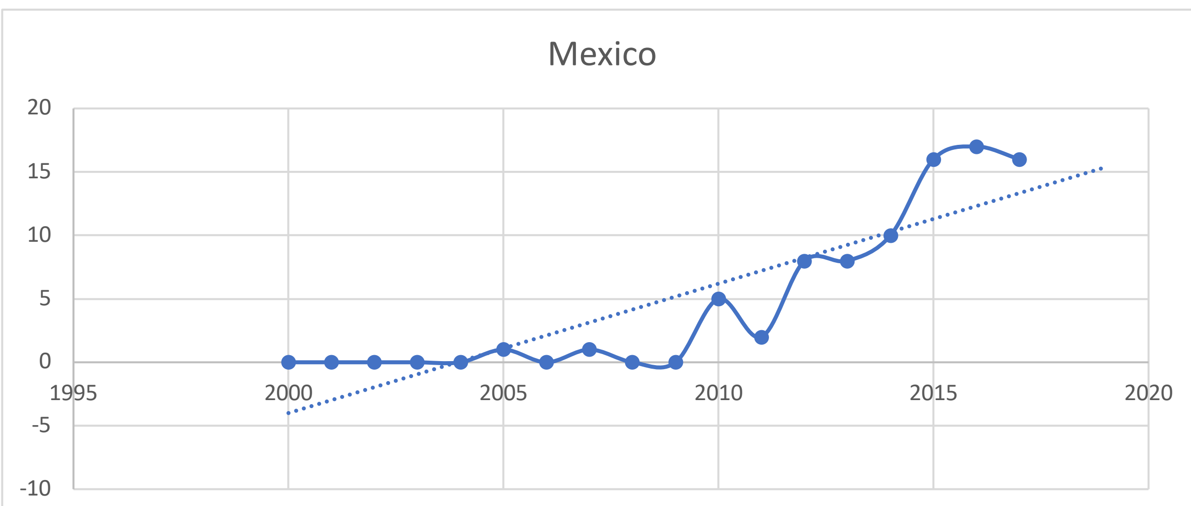
B.4: Linear Regression for UAE



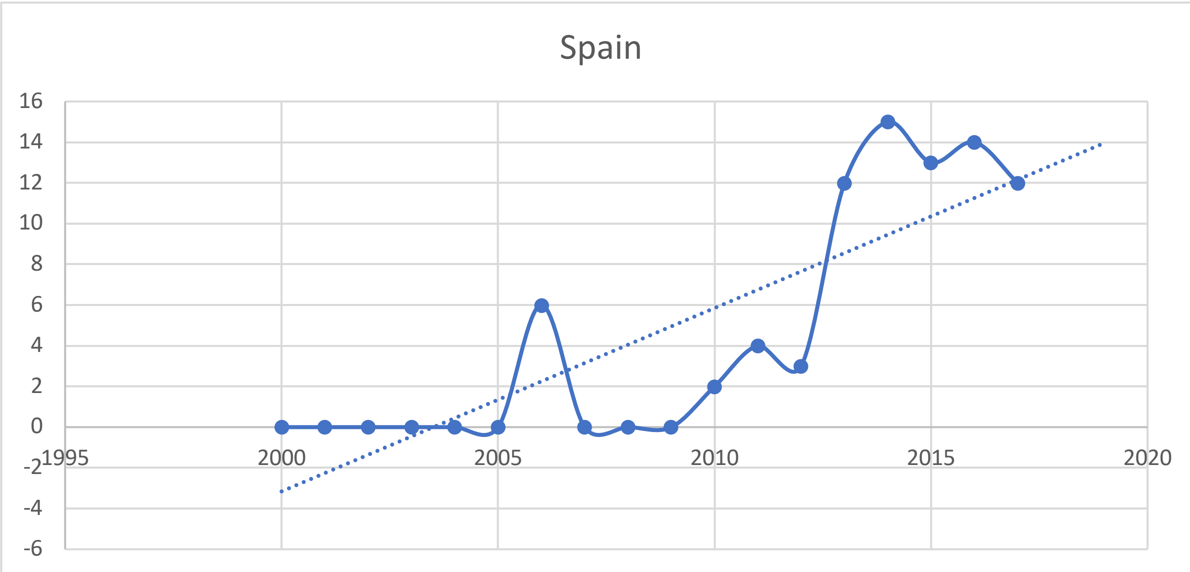
B.5: Linear Regression for Germany



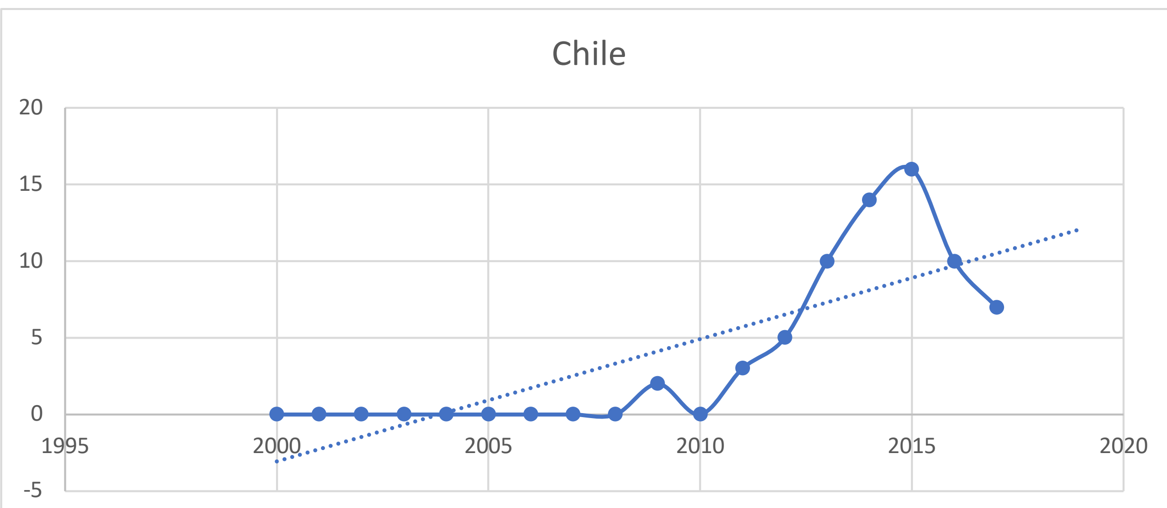
B.6: Linear Regression for Mexico



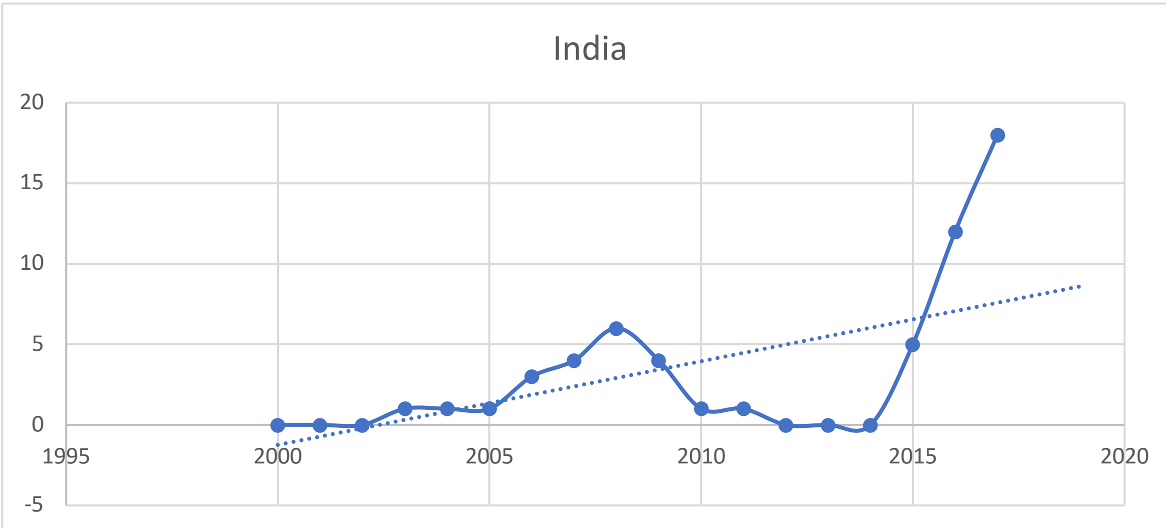
B.7: Linear Regression for Spain



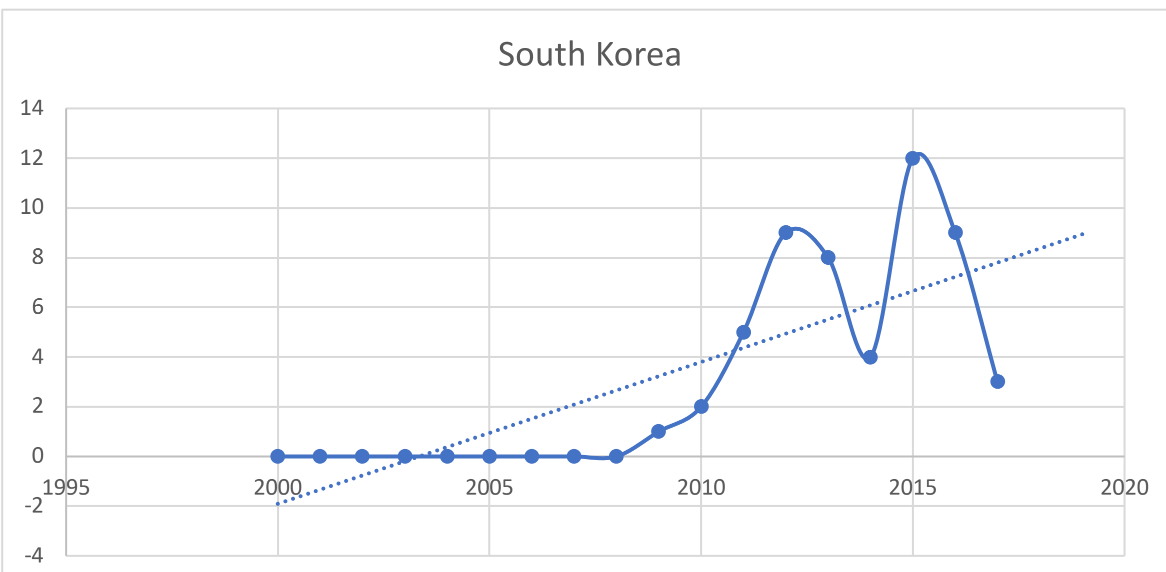
B.8: Linear Regression for Chile



B.9: Linear Regression for India

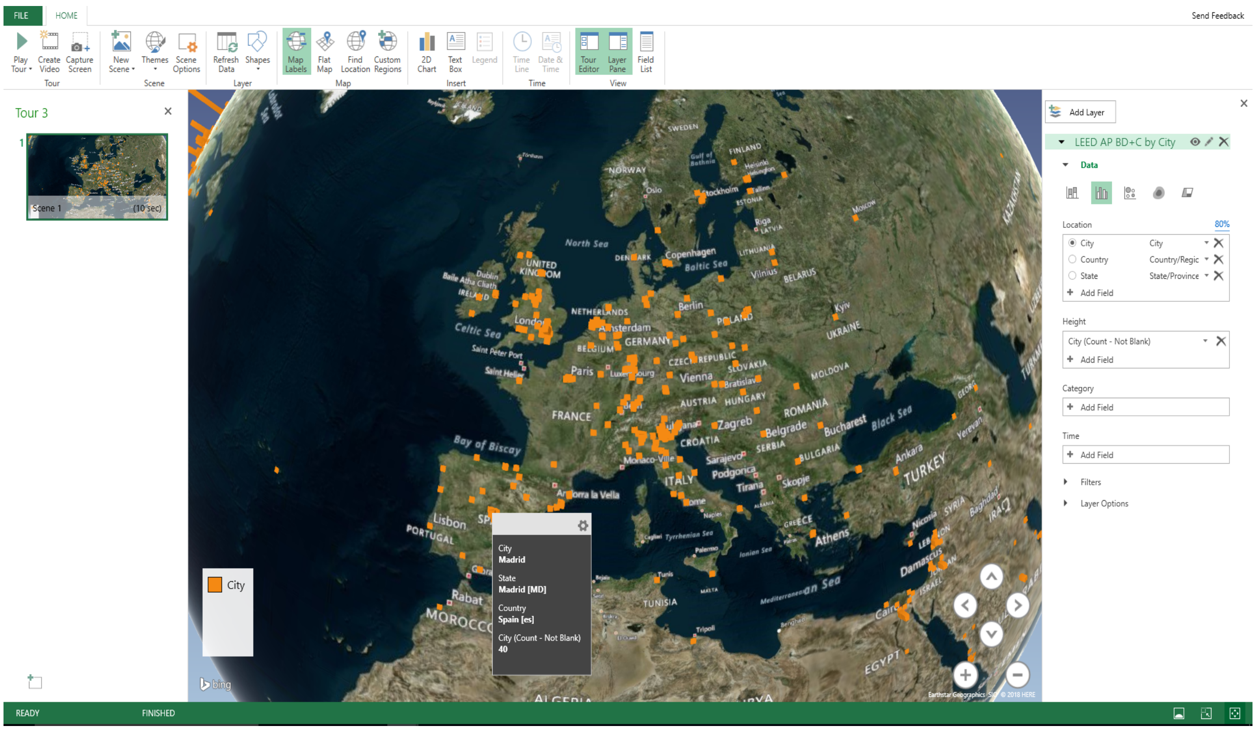


B.10: Linear Regression for South Korea

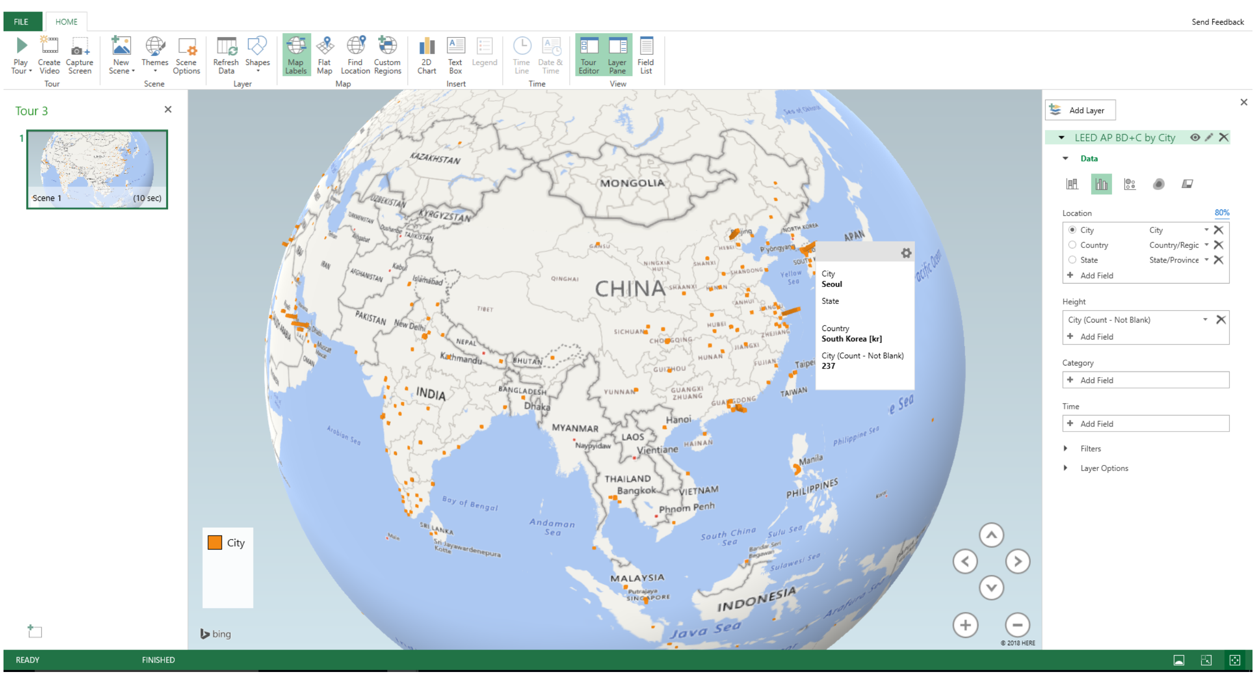


C. The following views were created from the big data source to display the number of LEED AP BD+C by continent in each city:

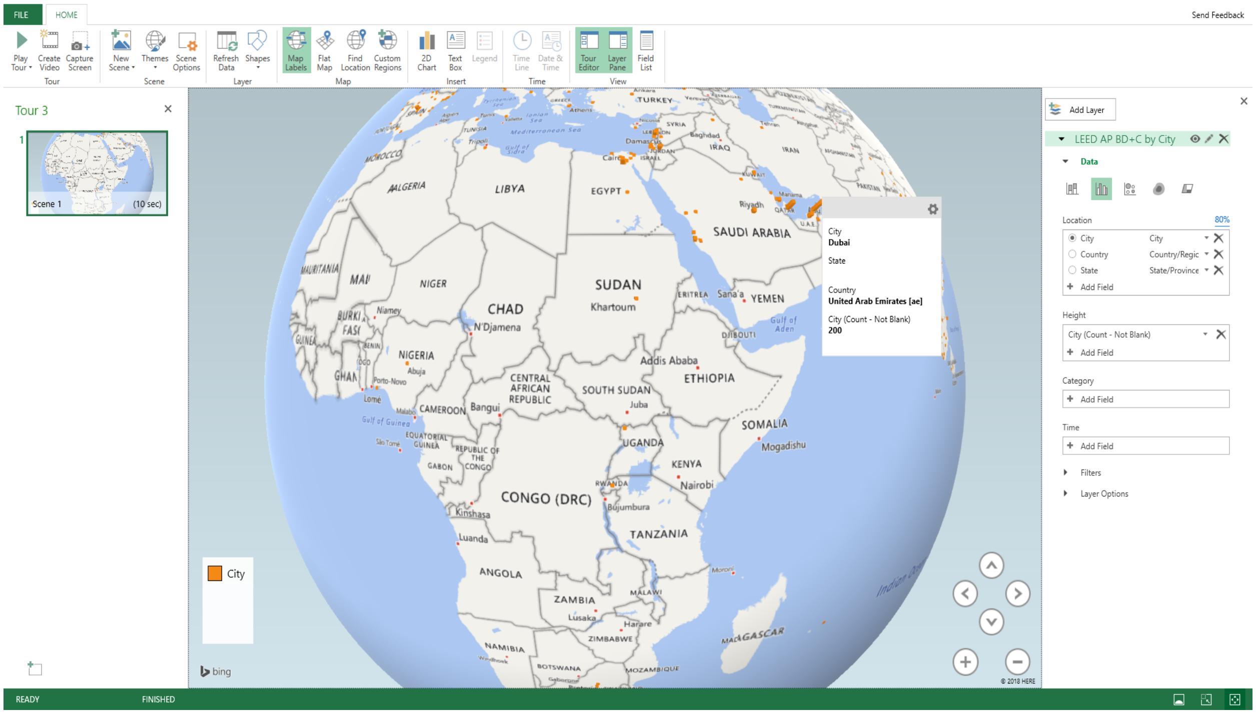
C.1: 3D Power Map of the Number of LEED AP BD+C by city in Europe



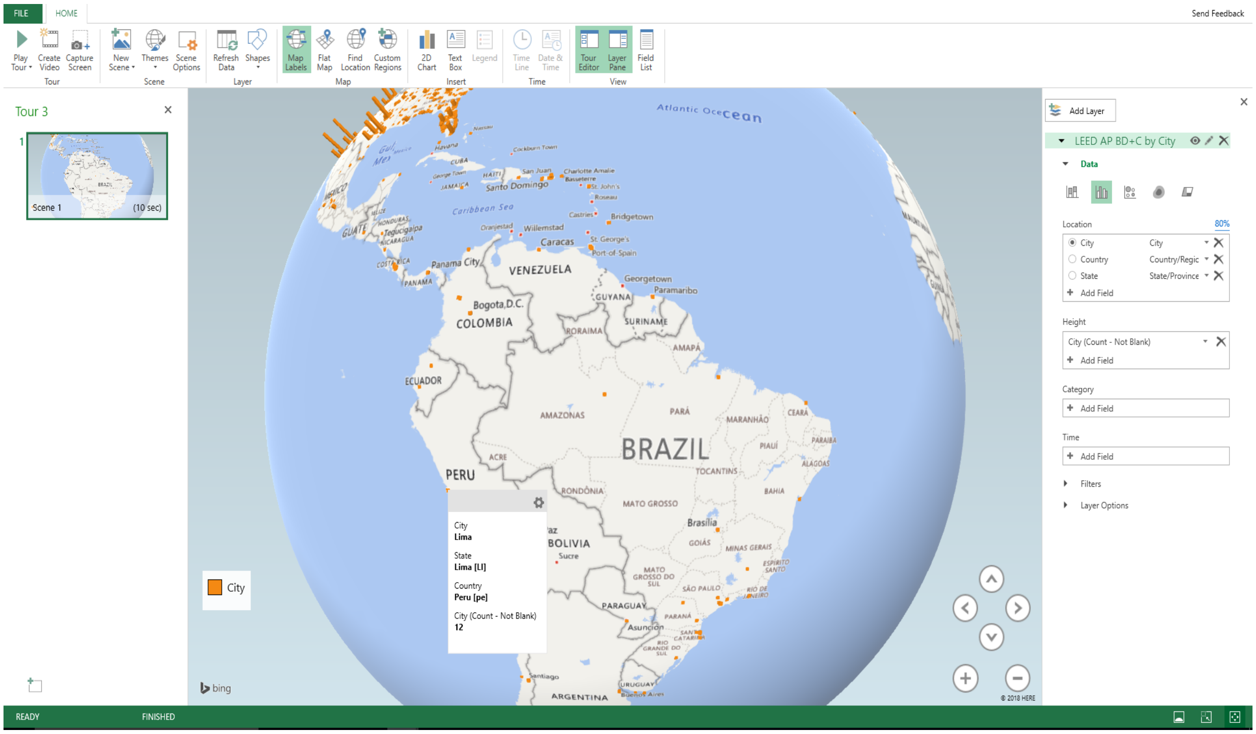
C.2: 3D Power Map of the Number of LEED AP BD+C by city in Asia



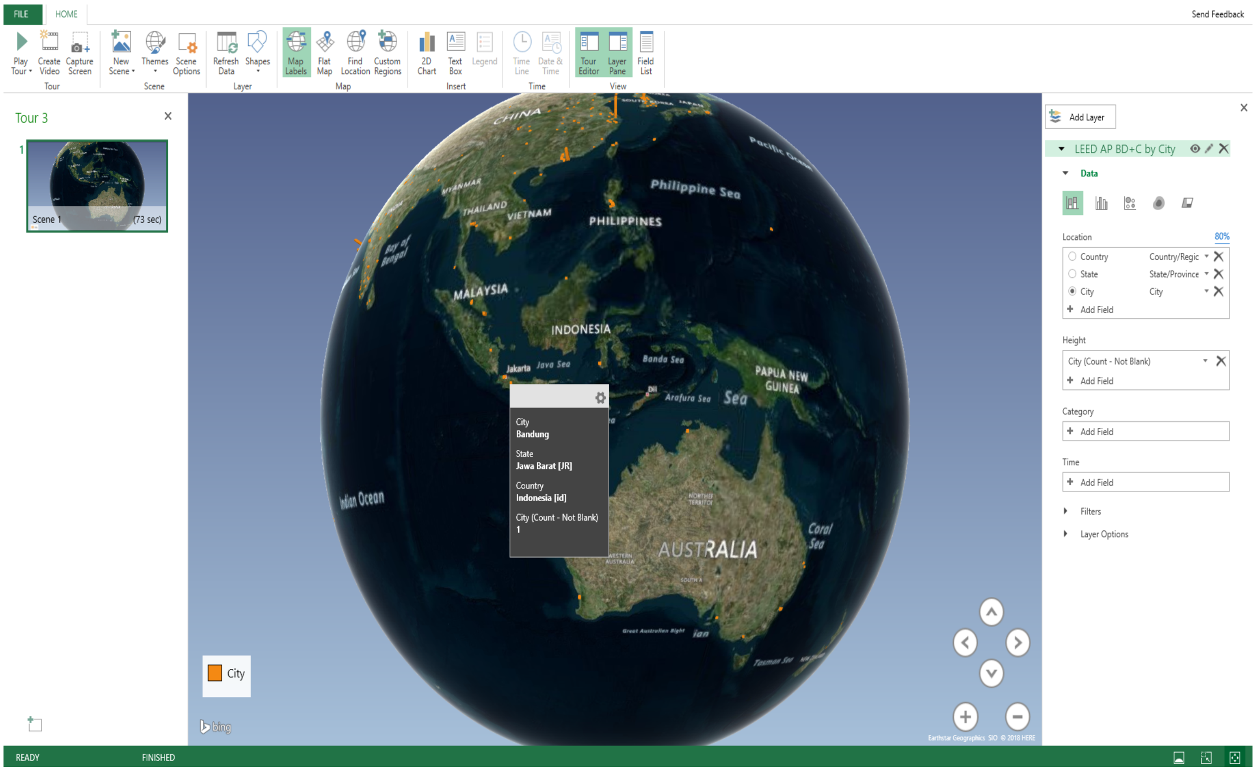
C.3: 3D Power Map of the Number of LEED AP BD+C by city in Africa



C.4: 3D Power Map of the Number of LEED AP BD+C by city in South America



C.5: 3D Power Map of the Number of LEED AP BD+C by city in Australia



D. Analysis performed under 41 sustainable actions provided by the Construction Industry Institute (CII) of labor in relation to the LEED code.

1. Leadership Team Staffing for Sustainable Projects

Description: Employ administrative staff that possess skills and experience in the management of sustainable projects. Identify lacking knowledge inside the company and be prepared to offer training on projects with a focus on environment/community impacts, worker safety cultures, and effective project communication (Azada, 2013).

Construction Function: Project Management

Economic Impact Magnitude: 2

Category of Metric: Benchmarking

****

Activity: Employ a LEED Accredited Professional (AP) certified worker inside the company

LEED Credit: Innovation Credit, LEED AP

Sustainable Practice: According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $84,770/year. LEED AP Exam I and II combined: $550 (USGBC) in-house.

$84,770 + $550 = $85, 320

According to PayScale forum, a Civil Engineer LEED AP salary in 2017 is $84,115/year.

Regular Practice: According to the US Bureau of Labor Statistics, median wage for Civil Engineers salary in 2017 is $84,770/year.

Analysis: $85,320 / $84,770 = 1.0065 < 1.1

$84,115/ $84,770 = 0.9923 < 1.1

Ratio < variation of 10%, ok. Minimal additional cost

Construction Stage: Front-End Planning

2. Community Social Responsibility Program

Description: Consider establishing a formal community social responsibility program as a way to respond to stakeholder needs. Related volunteer-based programs can have a significant impact as well. This responsibility program should include the development and maintenance of a project website for the local community and the establishment of community forums to discuss project issues (Jassawalla, 2004).

Construction Function: Project Management

Economic Impact Magnitude: 2

Category of Metric: Community or User Satisfaction

****

Activity: the establishment of community forums to discuss project issues

LEED Credit: Innovation Credit

Sustainable Practice: Community forums can increase the level of organization in a project. According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. For this case study, CII allocated 4 hours for a Civil Engineer to develop a community forum.

$40.70 x 4hours = $162.80/month

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action.

Construction Stage: Operations and Management

3. Contractor Sustainability Program and Recognition System

Description: The project team and its subcontractors/suppliers should establish and implement a sustainability program with a recognition system that rewards innovation and effectiveness. Identify sustainability program responsibilities and performance expectations for key personnel. Provide rewards for sustainability performance that meets or exceeds program expectations. The reward program should address all three dimensions of sustainability.

Construction Function: Project Management

Economic Impact Magnitude: N/A

Category of Metric: Benchmarking, Work Processes

****

Activity: Implement a sustainability rewards program inside the company (i.e. recognition for groups of employees that spend less electricity)

LEED Credit: Innovation Credit

Sustainable Practice: Economic savings produced in overhead and reduction of waste costs. This action also includes cost of incentives. According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. Implementing a sustainable reward program should not take more than a few hours for a Civil Engineer to develop. For this case study, CII allocated 2 hours for a Civil Engineer to develop a sustainable reward program.

$40.70 x 2hours = $81.40/month

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action.

Construction Stage: Operation and Management

4. Sustainability Provisions in Construction Execution Plans

Description: Incorporate sustainability provisions and solutions in the construction execution plans that are similar to provisions for safety, quality, cost, schedule, and resource management. Confirm that the team understands any sustainability specifications and assign responsibility and commitments for documentation.

Construction Function: Project Management

Economic Impact Magnitude: 3

Category of Metric: Benchmarking, Contracting and Procurement

****

Activity: Employ a LEED Accredited Professional (AP) certified worker inside the company

LEED Credit: Innovation Credit, LEED AP

Sustainable Practice: According to PayScale forum, median wage for Civil Engineers in 2017 is $74,637/year. LEED AP Exam I and II combined: $550 (USGBC) in-house. $74,637 + $550 = $75, 187.

According to PayScale forum, a Civil Engineer LEED AP salary in 2017 is $84,115/year.

Regular Practice: According to PayScale forum, median wage for Civil Engineers salary in 2017 is $74,637/year.

Analysis: $75,187 / $74,637 = 1.007 < 1.1 (in-house possess minimal additional cost)

$84,115/ $74,637 = 1.12 < 1.1 (above 10% cost)

Ratio < variation of 10%, ok. Minimal additional cost

Construction Stage: Front-End Planning

5. Sustainability Risk Management

Description: Ensure that sustainability risks are incorporated into the project risk management process by addressing environmental, social, and economic threats. Perform a sustainability risk assessment to identify sources and root causes of accidents, releases or spills of hazardous material. Mitigation measures should be developed and employed to minimize negative sustainability impacts (Yilmaz, 2010).

Construction Function: Project Management

Economic Impact Magnitude: 3

Category of Metric: Benchmarking

****

Activity: Perform a sustainability risk assessment

LEED Credit: Sustainable Site Credit, Site Assessment

Sustainable Practice: This activity helps ensure that all LEED credits, that are expected, can be achieved. According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. A sustainability risk assessment should not take more than a few hours for a Civil Engineer to develop. For this case study, CII allocated 4 hours for a Civil Engineer to perform a sustainability risk assessment (CTDOT, 2009).

$40.70 x 4hours = $162.80/month

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Design

6. Stakeholder Engagement Plan

Description: Lack of effective and timely stakeholder engagement can often lead to heightened sustainability-related risks. Formally assess and monitor the needs, interests, concerns, and expectations of external stakeholders that possess high interest and potentially high influence.

Construction Function: Project Management

Economic Impact Magnitude: N/A

Category of Metric: Community or User Satisfaction

****

Activity: Develop and implement an engagement plan for the stakeholder

LEED Credit: Integrative Process Credit

Sustainable Practice: Manage stakeholders' expectation is already part of the work performed by a Civil Engineer. According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. An engagement plan for the stakeholder should not take more than a few hours for a Civil Engineer to develop. For this case study, CII allocated 2 hours for a Civil Engineer to implement an engagement plan for the stakeholder.

$40.70 x 2hours = $81.40/month

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Front-End Planning

7. Site Work Hour Schedule to Reduce Traffic Impacts

Description: Analyze traffic impacts for different site work hour schedules, particularly during rush hour periods. Consider limiting construction work hours to better accommodate traffic flow during rush hour periods. Also consider noise and light effects when establishing site work hours and truck delivery hours that are compatible with local community concerns.

Construction Function: Benchmarking, Community or User Satisfaction

Economic Impact Magnitude: 2

Category of Metric: Work Processes, Environmental Footprint

****

Activity: Implement car-pooling

LEED Credit: Location and Transportation Credit

Sustainable Practice: This action can be organized by any employee inside a construction company. Implement car-pooling should not take more than a few hours for a regular employee to develop. For this case study, CII allocated 2 hours for a regular employee to implement car-pooling. $7.25 (minimum wage average according to US Bureau of Labor Statistics) x 2hours = $14.50/month

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Construction

8. Work Schedule to Reduce Electricity Impacts

Description: Modify the field work schedule to reduce electricity consumption and the associated environmental impacts of electricity consumption.

Construction Function: Project Management

Economic Impact Magnitude: N/A

Category of Metric: Work Processes, Environmental Footprint

****

Activity: Light bulbs changed to LED

LEED Credit: Energy and Atmosphere Credit, Reduce Energy Consumption

Sustainable Practice: Level of knowledge for the installation of the LED fixture is the same as a regular light bulb. Therefore, the implementation of this action possesses no additional cost.

Regular Practice: Level of knowledge for the installation of the LED fixture is the same as a regular light bulb, there is no additional expenses in this activity for labor.

Construction Stage: Design and Construction

9. Paperless Communication and Construction Documentation

Description: Replace hardcopy-based communication with electronic/digital forms wherever possible. Consider developing and implementing digital data collection systems and real-time field reporting technologies to streamline traditional paper-based processes and further reduce the reliance on paper files, drawings, and other documents during construction.

Construction Function: Project Management

Economic Impact Magnitude: 3

Category of Metric: Work Processes

****

Activity: distributing meeting materials electronically, arranging meetings by telephone or internet to reduce travel. If printing is required, modify the default setting of the printer to print double-sided and encourage recycling of all documents.

LEED Credit: LEED recommendation

Sustainable Practice: Economic savings are produced in overhead costs and travel expenses. Internet meeting software is not free but attending a meeting can generate expenses through time and energy consumed.

Internet meeting software, according to Skype business = $45/month

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Front-End Planning, Design, Construction, Operation and Maintenance

10. Construction Team Sustainability Performance Assessment

Description: Assess the sustainability performance of the construction management team during construction and after project completion. Consider including a sustainability performance section within the construction progress report, and in the close-out report that indicates annual sustainability goals, accomplishments, intermediate lessons learned, recommendations, and suggestions for additional improvements (Darling, 2011).

Construction Function: Project Management

Economic Impact Magnitude: N/A

Category of Metric: Benchmarking

****

Activity: create sustainability reports inside the company and monitor results, i.e. LEED AP

LEED Credit: Innovation Credit, LEED AP

Sustainable Practice: According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is \$84,770/year LEED AP Exam I and II combined: \$550 (USGBC) in-house.

\$84,770 + \$550 = \$85,320

According to PayScale forum, a Civil Engineer LEED AP salary in 2017 is \$84,115/year.

Regular Practice: According to the US Bureau of Labor Statistics, median wage for Civil Engineers salary in 2017 is \$84,770/year.

Analysis: \$85,320 / \$84,770 = 1.0065 < 1.1

\$84,115/ \$84,770 = 0.9923 < 1.1

Ratio < variation of 10%, ok. Minimal additional cost

Construction Stage: Operation and Management

11. Verification of Sustainability Claims and Ratings

Description: Review the credibility of sustainability claims of vendors and suppliers (such as certifications or comparative metrics) to facilitate prequalification and/or selection. Consider developing a verification procedure that can be replicated as necessary (FECCA, 2011).

Construction Function: Contracting

Economic Impact Magnitude: N/A

Category of Metric: Contracting and Procurement

****

Activity: Review sustainability material, labor, and equipment vendors and create database for future use.

LEED Credit: LEED Recommendation

Sustainable Practice: This activity can reduce costs by improving the level of organization in a construction company. According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. The creation of a database the includes sustainability vendors should not take more than a few hours for a Civil Engineer to develop. For this case study, CII allocated 2 hours for a Civil Engineer to create a database for future use.

$40.70 x 2hours = $81.40/month

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Operation and Management

12. Sustainability-friendly Project Subcontractors

Description: The traditional linear project delivery methods and contract agreements can undermine sustainability objectives and cause rework later in the project. Owners, with the help of contractors, should identify ways in which conventional project delivery models could be more sustainability-friendly. Contractors should understand the sustainability-enhancing additions to the contract, review warranties/liabilities associated with the implementation of sustainable construction methods and allocate risk and accountability fairly to stakeholders who can best control and mitigate those risks (Hageman, 2013).

Construction Function: Project Management

Economic Impact Magnitude: N/A

Category of Metric: Contracting and Procurement

****

Activity: Adopting sustainable delivery subcontractors

LEED Credit: Integrative Process

Sustainable Practice: Subcontractors are not part of a construction company employee database. Therefore, the implementation of this action possesses no additional cost.

Regular Practice: No further action

Construction Stage: Design

13. Promotion of Local Employment and Skills Development

Description: Use of participation targets for officially-established Small Business Enterprises (SBE), Women- owned Business Enterprises (WBE), and Minority Business Enterprises (MBE) can help promote local employment and local skills development (Ayoko, 2007).

Construction Function: Contracting

Economic Impact Magnitude: 2

Category of Metric: Contracting and Procurement

****

Activity: Promote diversity employment and hire personnel from local communities

LEED Credit: LEED Recommendation

Sustainable Practice: Several construction companies are committed to promote diversity during their hiring process. For example: Hawkins Construction and PCL Construction. Therefore, the implementation of this action possesses no additional cost.

Regular Practice: No further action

Construction Stage: Front-End Planning

14. Sustainability Change Proposal Clause

Description: Consider incorporating a Sustainability Change Proposal clause in the contract, similar to the Value Engineering Change Proposal clauses typically used. Consider giving the contractor the economic savings, leaving the environmental and social/community benefits to the owner (Mandelbaum, 2006).

Construction Function: Contracting

Economic Impact Magnitude: N/A

Category of Metric: Contracting and Procurement, Environmental Footprint

****

Activity: Sustainability Change Proposal Clause

LEED Credit: N/A

Sustainable Practice: Attorney needs to review the new sustainable clause for each project. Lawyer is not part of the construction company in the CII case study. According to the US Bureau of Labor Statistics the average wage of an attorney is $118,160 per year. Therefore, the implementation of this action possesses high additional cost.

Regular Practice: No further action

Construction Stage: Front-End Planning

15. Local Labor

Description: Some projects in remote regions are challenged with high local unemployment among an untrained, unproductive, and unsafe labor force. In these cases, tradeoffs between equipment-intensive and labor-intensive approaches must be examined. This decision can have significant impacts on safety, productivity, economics, local employment, skills training, local economics, and imported labor accommodations, among other concerns (Ayoko, 2007).

Construction Function: Field Engineering and Project Management

Economic Impact Magnitude: 3

Category of Metric: Contracting and Procurement, Labor & Staff

****

Activity: Hiring employees from local communities.

LEED Credit: LEED Recommendation

Sustainable Practice: Hiring local employees eliminates the cost of bringing foreign workers to a project. This activity will also improve the relationships inside community forums. The implementation of this action possesses no additional cost.

Regular Practice: No further action

Construction Stage: Front-End Planning

16. Pre-assembly and Pre-fabrication of Construction Elements

Description: Evaluate the environmental and community impacts from different approaches to construct-optional jobsite or near-jobsite pre-fabrication/pre-assembly/pre-coating. Consider issues such as fabrication site location, safety, local employment, reduction of scaffolding, work process productivity, and reduced waste generation.

Construction Function: Field Engineering

Economic Impact Magnitude: 3

Category of Metric: Benchmarking, Construction & Demolition Waste

****

Activity: applying coatings in a shop environment prior to final installation in order to avoid exposures and excess material use

LEED Credit: Material and Resources Credit, Building Product Disclosure and Optimization – Material Ingredients

Sustainable Practice: A prefabrication approach will create an easier installation rather than one on the field. The sustainable approach reduces the risk of construction failure. The implementation of this action possesses no additional cost.

Regular Practice: Same amount of effort between the sustainable and regular practice.

Construction Stage: Construction

17. Sequence and Route Planning for Project Transport

Description: Offsite and onsite project transport quantities, modes, sequences, routes and other site logistical parameters should be rigorously analyzed prior to site mobilization to determine environmental/community effects and sustainability-enhancing opportunities. Considerations should include new traffic generated, driver safety, timing of traffic, traffic-generated emissions, roadway damage and neighborhood input

Construction Function: Field Engineering

Economic Impact Magnitude: N/A

Category of Metric: Contracting and Procurement, Environmental Footprint

****

Activity: Route planning for project transport

LEED Credit: N/A

Sustainable Practice: Shipping all at once than rather item by item; more trips will have a greater impact in the environment. The implementation of this recommendation possesses no additional cost.

Regular Practice: No further action

Construction Stage: Construction

18. Minimization of Project’s Footprint of Disruption

Description: Avoid unnecessary damage to existing infrastructure and minimize the footprint of disruption associated with construction operations. Consider specifying and marking/flagging areas of the site that should be kept free of traffic, equipment, and storage and designate access routes and parking. Consider selecting technology and grading methods that are as low-impact as possible and that reduce damage to existing working surfaces.

Construction Function: Field Engineering, Construction Equipment Management

Economic Impact Magnitude: N/A

Category of Metric: Environmental Footprint

****

Activity: Utilization of wheeled versus tracked earthmoving equipment (backhoe) to minimize pavement surface damage

LEED Credit: N/A

Sustainable Practice: According to the US Bureau of Labor Statistics, median wage of a backhoe operator with wheels is $22.15/hr in 2017.

Regular Practice: According to the US Bureau of Labor Statistics, median wage of a backhoe operator with tracks is $22.15/hr in 2017.

Analysis: $22.15/$22.15/ = 1< 1.1

Ratio < variation of 10%, ok. No additional cost.

Construction Stage: Construction

19. Sustainable Material Substitutions

Description: Review material substitutions (where contractually allowable and beneficial) and be aware of sustainability-friendly substitution options. Encourage the use of the following: materials that have high recycled content, low-emitting/VOC-free, FSC-certified (for wood products), and materials that are manufactured from rapidly renewable resources (Agyekum, 2013).

Construction Function: Field Engineering

Economic Impact Magnitude: N/A

Category of Metric: Environmental Footprint

****

Activity: Installation of wood from the Forest Stewardship Council (FSC) for flooring

LEED Credit: Material and Resources Credit, Building Product Disclosure and Optimization – Sourcing of Raw Materials

Sustainable Practice: According to the US Bureau of Labor Statistics, median wage of an FSC Wood Floor Installer is $19.35/hr in 2017.

Regular Practice: According to the US Bureau of Labor Statistics, median wage of a wood floor installer is $19.35/hr in 2017.

Analysis: $19.35/$19.35 = 1< 1.1

Ratio < variation of 10%, ok. No change

Labor has no additional cost, but sustainable materials generally possess limited availability and present a higher price.

Construction Stage: Construction

20. Construction Noise Abatement and Mitigation

Description: Consider developing and implementing noise abatement and mitigation procedures. Identify site- specific mechanical/operational elements that are primary sources of these disturbances and assess their impacts on sensitive areas adjacent to the project site.

Construction Function: Field Engineering, Site Facilities and Operations

Economic Impact Magnitude: 2

Category of Metric: Environmental Footprint, Community or User Satisfaction

****

Activity: Haul trucks to move in one loop direction, to minimize the noise of reverse

LEED Credit: N/A

Sustainable Practice: The application of this recommendation with reduce the noise level at a construction site. The implementation of this action possesses no additional cost.

Regular Practice: No further action

Construction Stage: Construction

21. Selective Demolition versus Conventional Demolition

Description: Analyze the impacts of selective demolition as an alternative to conventional demolition methods. Consider the implications of sending mixed recyclables to a recycling center versus onsite sorting of recyclable materials.

Construction Function: Field Engineering, Site Facilities and Operations

Economic Impact Magnitude: 3

Category of Metric: Construction & Demolition Waste

****

Activity: Implement a recycling program at the construction site

LEED Credit: Material and Resources Credit, Storage and Collection of Recyclables

Sustainable Practice: The creation of a recycling program is necessary as a sustainable practice and as a regular practice too. Therefore, the implementation of this action possesses no additional cost.

Regular Practice: Recycling program is necessary as a regular practice.

Construction Stage: Construction

22. Sustainable Large-scale Earthwork and Grading Operations

Description: Employ a balanced earthwork strategy that minimizes the transportation/placement of excavated soils at offsite locations. Thoroughly evaluate cut and fill requirements to determine the most suitable mix of resources/work sequence and identify opportunities to reuse excavated soils. Consider further improving grading operations by utilizing GPS technologies in lieu of conventional staking methods, to perform soil volume checks, reduce rework, and improve overall operational efficiency (Kourmpanis, 2008).

Construction Function: Field Engineering, Materials Management

Economic Impact Magnitude: 3

Category of Metric: Construction & Demolition Waste

****

Activity: Utilizing sustainable strategies for earthwork such as GPS

LEED Credit: N/A

Sustainable Practice: According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. For this case study, CII allocated 4 hours for a Civil Engineer to develop a sustainable strategy of earthwork (Han, 2006):

$40.70 x 4hours = $162.80/month

No considerable changes in labor, $16.75/hr for earthwork operator using a GPS.

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No considerable changes in labor, $16.75/hr for earthwork operator.

Construction Stage: Construction

23. Reusable Shoring, Formwork, and Scaffolding

Description: When the use of shoring, formwork, and scaffolding system is unavoidable, consider the economic and sustainability benefits associated with durable, reusable systems.

Construction Function: Field Engineering

Economic Impact Magnitude: 3

Category of Metric: Work Processes, Construction & Demolition Waste

****

Activity: Scaffolding versus temporary wood structures

LEED Credit: N/A

Sustainable Practice: Scaffolder falls under the construction laborer category. According to the US Bureau of Labor Statistics, the median wage of a construction laborer in 2017 is $18.70/hr. The number of working hours is minimized by half compared to temporary wood structures, because reusable scaffolding can be assembled and disassembled quicker than one-time wood structures. Therefore, the implementation of this action possesses a reduction of cost.

Regular Practice: Temporary wood structure falls under the construction laborer category. According to the US Bureau of Labor Statistics, the median wage of a construction laborer in 2017 is $18.70/hr.

Construction Stage: Construction

24. Protection of Cultural Artifacts and Endangered Species

Description: Plan to protect cultural/historical artifacts and endangered species, if their presence is suspected or possible. Develop a recovery response plan in the event that such unexpected encounters occur during construction. Prior to site mobilization, identify, document, and prioritize the natural and cultural attributes that are to be protected, conserved, or restored.

Construction Function: Sites facilities and Operations, Field Engineering

Economic Impact Magnitude: 2

Category of Metric: Benchmarking

****

Activity: Design a plan to protect sensitive areas

LEED Credit: Sustainable Site Credit, Site Development – Protect or Restore Habitat

Sustainable Practice: The creation of a plan to protect sensitive areas is necessary as a sustainable practice and as a regular practice too. Therefore, the implementation of this action possesses no additional cost.

Regular Practice: A protection plan is required as a regular practice.

Construction Stage: Design

25. Protection of Trees and Vegetation

Description: Consider developing a tree and vegetation protection plan to reduce environmental impacts on existing ecosystems. Designate site-sensitive areas where staging, stockpiling, and soil compaction is prohibited. Identify and mark trees that must be cut/removed versus trees that should remain and be protected.

Construction Function: Sites facilities and Operations

Economic Impact Magnitude: N/A

Category of Metric: Environmental Footprint

****

Activity: Design a vegetation plan to protect the environment

LEED Credit: Sustainable Site Credit, Site Development – Protect or Restore Habitat

Sustainable Practice: According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. For this case study, CII allocated 16 hours for a Civil Engineer to design a vegetation plan to protect the environment, flat fee:

$40.70 x 16hours = $651.20/project

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Construction

26. Sustainable Temporary Facilities

Description: Optimize the planning of temporary site facilities. Consider the sustainability impacts related to the scoping, sizing, location, and layout of the site.

Construction Function: Sites facilities and Operations, Field Engineering

Economic Impact Magnitude: 3

Category of Metric: Environmental Footprint

****

Activity: Sustainable design implementation before the start of the project through a LEED AP

LEED Credit: Sustainable Site Credit, Site Assessment

Sustainable Practice: According to the US Bureau of Labor Statistics, the median wage for Civil Engineers in 2017 is $84,770/year. LEED AP Exam I and II combined: $550 (USGBC) in-house.

$84,770 + $550 = $85,320

According to PayScale forum, a Civil Engineer LEED AP salary in 2017 is $84,115/year.

Regular Practice: According to the US Bureau of Labor Statistics, median wage for Civil Engineers salary in 2017 is $84,770/year.

Analysis: $85,320 / $84,770 = 1.0065 < 1.1

$84,115/ $84,770 = 0.9923 < 1.1

Ratio < variation of 10%, ok. Minimal additional cost

Construction Stage: Design

27. Source of On-Site Power for Temporary Site Facilities

Description: Optimize the planning of temporary site facilities. Consider the implications of sequencing temporary facilities and construction site aesthetics for some projects.

Construction Function: Sites facilities and Operations, Construction Equipment Management

Economic Impact Magnitude: N/A

Category of Metric: Environmental Footprint

****

Activity: Consider the sustainability impacts related to the scoping, sizing, location, and layout of temporary power generation, site lighting, and infrastructure tie-ins.

LEED Credit: N/A

Sustainable Practice: No further action, temporary site facilities are out of scope.

Regular Practice: No further action

Construction Stage: Design

28. Site Energy Management

Description: Optimize management of site energy by implementing computerized system control technologies and associated energy-reduction strategies. Manage phantom power consumption to reduce the consumption of energy further during periods of facility inactivity (Hanna, 2008).

Construction Function: Sites facilities and Operations

Economic Impact Magnitude: 3

Category of Metric: Environmental Footprint

****

Activity: Implementing thermal and motion control system.

LEED Credit: Energy and Atmosphere credit, Optimize Energy Performance

Sustainable Practice: According to Home Depot, an average motion/thermal control sensor is $15 (labor included). According to EPA, the average household has 45 light bulbs, replacing that number of thermal/motion detectors would save $180 per year.

45 x $15 = $675 - $180/year = $495/ household

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Operations and Maintenance

29. Indoor Air Quality Improvements

Description: Enhance the indoor air quality of both permanent and temporary facilities by avoiding contamination of HVAC systems, controlling pollutant sources, and interrupting contamination pathways, all during construction. Protect stored or installed absorptive materials from moisture damage. Avoid using permanently installed air handlers for temporary heating/cooling during construction (Joshi, 2009).

Construction Function: Sites facilities and Operations

Economic Impact Magnitude: N/A

Category of Metric: Facility Commissioning, Environmental Footprint

****

Activity: Building flush-out and test air contaminant levels

LEED Credit: Indoor Environmental Quality Credit, Indoor Air Quality Assessment

Sustainable Practice: On average, additional $35 per vent (work performed by a subcontractor)

Regular Practice: Building flush out not required

Analysis: Additional expense of $35/vent (average home $300-$500). Therefore, the implementation of this action possesses minimal additional cost.

Construction Stage: Construction

30. Collection, Remediation, and Reuse of Gray Water and Stormwater

Description: Consider the storage and treatment of gray water and/or harvested storm water for non-potable needs, such as sewage conveyance, vehicle washing, urinal and toilet flushing, custodial uses, landscaping, and dust control.

Construction Function: Sites facilities and Operations, Field Engineering

Economic Impact Magnitude: 2

Category of Metric: Construction & Demolition Waste, Environmental Footprint

****

Activity: Raingarden implementation

LEED Credit Water Efficiency Credit, Prerequisite Outdoor Water Use Reduction

Sustainable Practice: Professional installation typically costs approximately $10-$20 per square foot or $1500-$3000 for 150 square ft, depending on the complexity of the design, the amount and variety of the landscaping, and how the water is directed into the raingarden.

Therefore, the implementation of this action possesses high additional cost.

Regular Practice: Raingarden not required

Construction Stage: Construction

31. Environmentally-friendly Control of Dust

Description: Develop a dust control plan that incorporates environmentally-friendly methods and technologies. This includes building flush outs and test air contaminant levels.

Construction Function: Sites facilities and Operations, Field Engineering

Economic Impact Magnitude: 2

Category of Metric: Environmental Footprint, Community or User Satisfaction

****

Activity: Building flush-out and test air contaminant levels

LEED Credit: Indoor Environmental Quality Credit, Indoor Air Quality Assessment

Sustainable Practice: On average, additional $35 per vent (work performed by a subcontractor) Additional expense of $35/vent (average home $300-$500). Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: Building flush out not required

Construction Stage: Construction

32. Construction and Demolition Waste Management

Description: Going beyond regulatory requirements, describe waste reduction goals, and specify targets for waste and debris diversion. Prepare and formalize a Construction and Demolition Waste Management Plan that entail the following actions: reduce solid waste generation; identifies specific approaches to be used in recycling/reuse; presents the name and location of the landfill used for non-recyclable materials; list the materials that may be extracted/recycled/salvaged; and estimate the percentage of waste that will be diverted by this plan (establish metrics for measurement).

Construction Function: Sites facilities and Operations, Field Engineering

Economic Impact Magnitude: N/A

Category of Metric: Construction and Demolition Waste

****

Activity: Prepare and formalize a Construction and Demolition Waste Management Plan

LEED Credit: Material and Resources Credit, Construction and Demolition Waste Management Planning

Sustainable Practice: Waste management plan required as a sustainable practice. According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. For this case study, CII allocated 8 hours for a Civil Engineer to develop a waste management plan.

$40.70 x 8hours = $325.60/project

Therefore, the implementation of this action possesses minimal additional cost, but no additional cost is included overall because this is a requirement as a regular practice too.

Regular Practice: Waste management plan required as a regular practice.

Construction Stage: Construction

33. Collection, Sorting, and Recycling of Construction Wastes

Description: Consider the active collection and sorting of construction wastes to facilitate reuse or recycling. Targeted materials may include asphalt, concrete, soil, electrical conduit/wires, wood, paper products, plastic, and paints, among others. In addition, consider performing time-phased recycling whereby specific waste materials can be extracted and separated for recycling during optimal construction stages.

Construction Function: Sites facilities and Operations, Field Engineering

Economic Impact Magnitude: N/A

Category of Metric: Construction and Demolition Waste

****

Activity: the recycling of wood and gypsum wall board can be optimized during the framing and sheet-rocking stages of construction.

LEED Credit: Material and Resources Credit, Storage and Collection of Recyclables

Sustainable Practice: No further action, recycling is already part of traditional practices but the cost of recycling can increase if a community for instance does not possess recycling capabilities for a type of material (ie: glass).

Regular Practice: No further action, recycling is already part of a traditional practices.

Construction Stage: Construction

34. Reduction of Packaging Waste

Description: Consider reducing packaging waste through vendor participation, using bulk packaging techniques, and selecting products with minimal or no packing. Identify suppliers who can deliver materials in sturdy containers with adequate packing materials and require them to reclaim/back-haul empty shipping containers for reuse and recycling. Reuse non-returnable containers on the jobsite to the maximum extent possible.

Construction Function: Sites facilities and Operations, Materials Management

Economic Impact Magnitude: N/A

Category of Metric: Construction and Demolition Waste

****

Activity: Identification of vendors that include minimal packaging

LEED Credit: Material and Resources

Sustainable Practice: This action can be organized by any employee inside a construction company. Identification of vendors that include minimal packaging does not take more than a few hours for a regular employee to develop. For this case study, CII allocated 2 hours for a regular employee to implement this activity.

$7.25 (minimum wage average according to US Bureau of Labor Statistics) x 2hours = $14.50/month

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Front-End Planning

35. Material and Equipment Handling Strategy

Description: Double handling of material and equipment can be a major cause of project waste and energy consumption. Addressing this issue is particularly important for large complex projects on which loss of essential components can have a significant impact on construction processes and the project schedule.

Construction Function: Construction Equipment Management

Economic Impact Magnitude: 3

Category of Metric: Contracting and Procurement, Equipment

****

Activity: Employ an automated construction material tracking and warehouse management system

LEED Credit: N/A

Sustainable Practice: Only applies to complex and industrial projects, not residential or commercial. Not applicable.

Regular Practice: Only applies to complex and industrial projects, not residential or commercial.

Construction Stage: N/A

36. Minimization of Material Surplus

Description: Employ tight quantity estimation to minimize the generation of material surplus. Ensure that only the correct amount of materials is purchased and delivered to the site. For example, order 80% of the needed materials during the design phase, and only order the remaining amount later in the project after quantities are well understood.

Construction Function: Materials Management, Contracting

Economic Impact Magnitude: 3

Category of Metric: Work Processes, Construction & Demolition Waste

****

Activity: Ordering construction material to the site using a tight quantity estimation (ie: brick analysis). Ordering 80% of the bricks for a construction site first and then, order the remaining material.

LEED Credit: N/A

Sustainable Practice: Tight quantity estimation, on average the sustainable practice saves construction work by at least 5%. Therefore, the implementation of this action possesses savings.

Regular Practice: Ordering 105% of the total material

Construction Stage: Construction

37. Selection and Replacement of Construction Equipment

Description: Develop and employ an environmentally conscious policy heavy construction equipment acquisition and replacement, to improve the emissions performance of the heavy construction equipment fleet (Bennick, 2012).

Construction Function: Construction Equipment Management

Economic Impact Magnitude: 2

Category of Metric: Equipment

****

Activity: Promote the progressive improvement of reduction of emissions

LEED Credit: LEED Recommendation

Sustainable Practice: According to the US Bureau of Labor Statistics, median wage for Civil Engineers in 2017 is $40.70/hour. For this case study, CII allocated 4 hours for a Civil Engineer to develop a strategy to reduce the emissions of machinery:

$40.70 x 4hours = $162.80/month

No considerable changes in labor, $16.75/hr for machine operator producing less emissions.

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No considerable changes in labor, $16.75/hr for machine operator.

Construction Stage: Construction

38. Right-sizing of Construction Equipment

Description: Consider the right-size of construction equipment, recognizing cost, availability, convenience, capacity, and sustainability aspects. Consider leasing or renting of any equipment not currently owned (Navon, 2010).

Construction Function: Construction Equipment Management

Economic Impact Magnitude: 3

Category of Metric: Contracting and Procurement, Equipment

****

Activity: Consider the right-size of construction equipment, recognizing cost, availability, convenience, capacity, and sustainability aspects.

LEED Credit: LEED Recommendation

Sustainable Practice: Recommendation that can be implemented to any construction project. The implementation of this action possesses savings for the construction company.

Regular Practice: No further action

Construction Stage: Design

39. Inspection and Maintenance of Subcontractor Construction Equipment

Description: Develop and apply a systematic construction equipment inspection for subcontractors to reduce environmental impacts associated with inefficient equipment performance, equipment breakdowns, and the spill of hazardous fluids. Consider establishing a dedicated centralized area, in lieu of satellite locations, to provide one location for regular equipment inspection, maintenance, and repair services (Leech, 2012).

Construction Function: Construction Equipment Management

Economic Impact Magnitude: N/A

Category of Metric: Equipment

****

Activity: Maintenance inspections of subcontractor equipment.

LEED Credit: LEED Recommendation

Sustainable Practice: Not applicable. Analysis does not include work done for subcontractors.

Regular Practice: No further action.

Construction Stage: Operations and Maintenance

40. Quality Management and Facility Start-Up Planning

Description: Plan field construction quality management, pre-commissioning, commissioning, initial operations, and other start-up-related activities in a manner that optimizes safety performance, environmental performance, and energy consumption during these stages. As part of these planning efforts, seek to optimize resource utilization and, if applicable, minimize the amount of rejected product resulting from initial manufacturing operations (Chester, 2009).

Construction Function: Quality Management, Commissioning, & Handover

Economic Impact Magnitude: 3

Category of Metric: Contracting and Procurement, Facility Commissioning

****

Activity: Optimize the equipment performance through commissioning when using solar panels.

LEED Credit: Energy and Atmosphere Credit, Fundamental Commissioning and Verification

Sustainable Practice: Sustainable equipment require more owner training and commissioning. According to the US Bureau of Labor Statistic, the average cost of an annual inspection for a household rooftop solar PV system is approximately $150 (Davies, 2013).

5 inspections per year (including training) x $150 = $750

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No further action

Construction Stage: Operations and Maintenance

41. Sustainability Lessons Learned

Description: Review sustainability performance as part of the post-implementation evaluation report. Consider holding a meeting with key stakeholders to identify sustainability successes, evaluate opportunities for improvements, and collect lessons learned for enhancing the sustainability of future projects. Consider this activity an opportunity for benchmarking the project's sustainability performance (Gormley, 2011).

Construction Function: Quality Management, Commissioning, & Handover

Economic Impact Magnitude: N/A

Category of Metric: N/A

****

Activity: Collection of lessons learned for future projects.

LEED Credit: LEED Recommendation

Sustainable Practice: Collection of lessons learned for future projects can be accomplish by 1 day (8 hours) of workshop per project for the engineer in charge. For this case study, CII allocated 8 hours for a Civil Engineer for a 1 day workshop.

$40.70 x 8hours = $325.60/project

Therefore, the implementation of this action possesses minimal additional cost.

Regular Practice: No requirements.

Construction Stage: Operations and Maintenance