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The Investigation Of The Practice Of Frugal Innovation Across Cultures And The Introduction Of An Instructional Model For Streamlining The Design Process

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DEDICATION

I dedicate this dissertation to my love ones…

to Mother for her boundless support in all my endeavors;

to Marcos for his guidance and encouragement through out life;

to Efren for having a blithesome spirit

to my friends and family for being inspirational and motivating me in all that I do.

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by

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DISSERTATION

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ABSTRACT

The central objectives of this dissertation are to analyze frugal innovation, apply foundational methodologies that contribute to product design, and discover the important contextual information for successful development. This dissertation describes a systematic procedure in designing frugally innovated products. The institutional design will encompass environmental, social, and economic impacts into the entire products' life cycle. Also, a comparison is made between two developing nations' contextual factors to reveal the formulation of frugal innovation.

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CHAPTER 1: INTRODUCTION

Since the start of the industrial revolution, many changes have occurred throughout humanity. No one could have foreseen the effects of the industrial revolution. These changes can be considered positive yet some may be thought of as detrimental. For example, Alexander Parkes in 1862 discovered plastic. He could not have foreseen the future of his creation. Consequentially, plastic manufacturers have been producing millions of tons over the past 150 years, resulting in the Great Pacific Garbage Patch, a Texas-size floating plastic-island in the middle of the Pacific Ocean (Knoblauch, 2009). Many evolutionary inventions and technological advances have originated with good intent, yet with unforeseeable negative effects (Nikolaidis, Mourelatos, & Pandey, 2011). Environmentally cautious information was unavailable at the time, therefore, the primary focus was profit. The current practices in manufacturing and usage of majority of products have unfavorable impacts on the environment. The environmental effects range from the excess generation of waste, the contamination of water, polluting of the atmosphere, and the depletion of natural resources. At the current rate industrial development threatens to exceed the limits of sustainability and poses impending threats to global climate and the quality of life on earth.

In order to achieve a sustainable future, an essential change of human mindset is needed. An obstacle for change is the integration of environmental issues into the political arena. In recent years, by allowing environmental disputes into political debates the fundamental reasons such as, the needs of the planet, have been lost in the deliberation (Mathaisel, Manary, & Criscimagna, 2013). Politicians mandating environment issues have various backgrounds, hence accompanied by different beliefs and agendas. Influential individuals, such as environmentalists,

gather data and present it to politicians who have the ability to implement laws. However, legislators are influenced by corporations, which are apprehensive for change and extremely protective of their economic interest. With these constant battles of influence we become jammed in disagreements and make insignificant environmental improvements. Yet another obstacle, lawmakers put aside forthcoming tribulations, such as climate change, in order to focus on more immediate problems in society. Therefore, environmental issues require a more attentive and approachable scheme.

This dissertation will present a unique system to increase economic, social, and environmental value through product design. Frugal innovation creates a distinct view of product development, different from the traditional design methods. The fundamental foundation in frugal innovation is the development of a product that incorporates environmental consciousness and social awareness. This strategy may be an alternative starting point to ultimately becoming a sustainable society. Frugal innovations may be considered a win-win situation with respect to profit and our planet, rather than the status quo of "give and take". A global understanding of frugal innovation will reveal opportunities to simultaneously improve social health, environmental problems, and company profitability.

1.1 STATE OF THE ENVIRONMENT

Environmental issues are defined as negative effects on to the natural world due to anthropogenic activities (Kaplan, n.d.). Mankind's need for products and luxury, have affected the natural world in multiple negative alterations, such as, irreversible damage towards climate change, non-renewable resource consumption, and ecosystems sustainability. Particularly,

impacting the environment through pollution classified as soil, radioactive, thermal, light, visual, and noise pollutants (Minghua & Yongzhong, 2011). Humans have not only reduced that amount of natural resources available but also affected entire genomes, organisms, and species (Van den Bergh, Truffer, & Kallis, 2011). The environment has been affected and is continuously altered by anthropogenic effects (González, Quesada, & Bahill, 2003).

Majority of scientists are consciously aware of the pandemic crisis awaiting life on earth if humanity continues on this path of eco-destruction. However, many are unaware of this inevitable situation. Suggested methodologies to improve environmental consciousness are sustainable, green, and environmentally conscious design process; if applied, these methods have the potential to improve environmental performance (Fiksel, 2009). Designers and engineers accept that a change in designing is an active step towards a sustainable future (Fiksel, 2009).

1.2 ENVIRONMENTAL PROBLEMS

Three major atmospheric pollution problems are identified as: global warming, urban and industrial pollution, and acidification. These problems are the fallouts due to the use of fossil fuels in energy production. The continual uses of fossil fuels threaten current levels of green house gases released into the atmosphere, along with harmful contaminants that effect life.

1.2.1 POLLUTION

Pollution is the introduction of contaminants into the environment most commonly created by human actions; which affects all living organisms by making it virtually impossible to

sustain life. The contaminants' effects are a larger problem than what the public is lead to believe. Pollution is one of the biggest killers in the world distressing over a hundred million individuals a year. The number of societies affected by pollution is comparable to the number of people affected by HIV and malaria worldwide (Kaplan, n.d.). Pollution harms the earth in three main categories land, water, and air.

Air pollution is the accumulation of hazardous substances into the atmosphere that have severe damaging effects. Air impurities are associated with numerous human health vulnerabilities, targeting pulmonary, cardiac vascular, neurological, and respiratory terminal diseases. Air toxins have the similar negative effects on animal life as it does on humans. Individuals that reside near or in highly polluted areas have a 20% higher risk of death from lung cancer compared to individuals residing in less-polluted areas (Minghua & Yongzhong, 2011). Air pollutant is neither stationary nor fenced-in by national boundaries, yet it is transported globally through winds and rain. The greenhouse effect is a process by which radiation from the surface is absorbed by the atmospheric greenhouse gases and re-radiated towards the surface, causing an increase in surface temperatures (Reinders, Diehl, & Brezet, 2013). Green house gases consist of water vapor, carbon dioxide, methane, sulfur dioxide, and ozone; inevitable byproducts of pollution. Currently, no climate model exhibits a possibility for air quality levels returning to pre-industrial levels. Industrial manufacturers, combustion, and power plants are the primary sources of atmospheric pollution. The harsh destructive effects and causes of atmospheric depletion are directly correlated with anthropogenic actions (Sharma & Iyer, 2012).

Pollution in the global water systems is the cause of fourteen thousand deaths per day (Fiksel, 2009). Water pollution not only affects people but also plants and whole biological communities. Water is referred as polluted when it is impaired by anthropogenic contaminates and is classified as undrinkable (Mathaisel et al., 2013). Water pollution is the introduction of chemicals that degrade the quality of life that lives and consumes it. The main contributors for water pollution are from factories, refineries, mining, and household chemicals.

Contaminates that cause water pollution range from chemicals, pathogens, physical, and sensory changes. Oxygen-deleting substances can affect the turbidity of the water causing disruptions in plant growth and the ability for fish to breath (Corsano, Iribarren, Montagna, Aguirre, & Suarez, 2006). Water pathogens affect the physical chemistry of the water by changing the pH, electrical conductivity, and temperature, causing eutrophication. Eutrophication is a large problem that affects the Gulf of Mexico (Mathaisel et al., 2013). The Mississippi River transfers 1.5 million metric tons of nitrogen toxicity from farmlands into the Gulf of Mexico, creating a "dead zone." The size of the dead zone is equivalent to the area of New Jersey. It is estimated that 46% of the lakes in America are too polluted for drinking, fishing, aquatic life, and swimming (Miettinen & Hämäläinen, 1997).

Pollution is a large problem for current and future life on this planet. Mankind has polluted the planet in all areas. Pollution is being released from industrial plants, power plants, vehicles, stoves, incinerators, burning, and aerosol sprays. The environmental issues discussed have a clear source, the greed and need of our society. The products we produce are a direct and indirect cause of the continued polluting of this planet. There is a need for the development and

the application of a design process that considers the well-being of planet earth's environment into every product and lifestyle.

1.2.2 Energy Issues

Currently the utilization of several energy sources range from renewable energy to non-renewable sources. Energy is utilized in the production of electricity, heating, and transportation. Among non-renewable energy sources, the most consumed are: oil, coal, and natural gas. The renewable energy consists of continually replenished resources. Out of the total amount the United States utilizes, 87% consists of non-renewable energy, while 13% is from renewable sources (Ehrenfeld, 2008).

Currently, natural resources are being consumed at an exponential rate (Shafiee & Topal, 2008). Fossil fuels are the primary limited-resource that is excavated for the production of energy. The world's daily energy consumption growth is predicted to reach a 53% increase by 2035 (Zecca & Chiari, 2010). Energy consumption across developing countries in the next 25 years is forecasted to increase 20%, (Corsano et al., 2006), along with emerging nations growth, which is expected to increase 80%, (Shafiee and Topal, n.d.). Four Earth sized planets will be needed to satisfy this demand if this trend continues.

An increasing appetite for products that feed into luxurious lifestyles attracts an accelerating demand for limited natural resources. Oil is the world's primary energy source. However, current reserves are estimated at 1,333 billion barrels worldwide, approximately lasting 46.2 years under current trends, (Shafiee and Topal, n.d.). To meet current global needs,

natural gas is estimated to diminish in 58.6 years with a 6,675 trillion cubic feet supply (Goldemberg, 2006), resembling a similar fate as oil reserves. Coal, however, is the most abundant of all fossil fuels. Currently, China and other developing nations are increasing their demand for coal. The estimated reserves of 4 trillion short tons will deplete in merely 188 years (Ruppert et al., 2002). The need for new energy sources as well as a reduction of current energy usage has become more apparent.

The limited availability of fossil fuels are not the sole reason for change. Detrimental environmental and health effects due to the burning of these fuels are worthy of further investigation. The use of fossil fuels worldwide releases two billion metric tons of pollution into the atmosphere per year (Paoletti et al., 2010). The current atmospheric levels of carbon dioxide is 380 parts per million (Åström, Tohka, Bak, Lindblad, & Arnell, 2013). However, if all fossil fuels are diminished, models estimate the atmospheric levels of carbon dioxide will quadruple to 1,423 parts per million (McNamara & Caulfield, 2011). The intergovernmental Panel on Climate Change (Baettig, Brander, & Imboden, 2008), concluded there exists a direct link between our energy consumption and global warming. World temperatures are predicted to raise 15 degrees Fahrenheit in the next 100 years as a direct result of greenhouse gases that are released through fossil fuels (Akerlof, Maibach, Fitzgerald, Cedeno, & Neuman, 2013). The effects of burning fossil fuels will be observed in climate changes, resulting in the melting of polar ice caps; ensuing an increase of sea level. The increase in temperature is predicted to cause major extremes such as droughts, heat waves, and storms. There may exist other unforeseen consequences due to the continuous use of fossil fuels.

1.2.3 CURRENT SOLUTIONS FOR ENVIRONMENTAL PROBLEMS

To solve the energy problems one might consider utilizing renewable energy. However, its viability depends on non-renewable sources being available and inexpensive. A second approach to reduce pollution is to reduce fossil fuel consumption. It has been seen that individuals will not reduce their energy use regardless of the expense to the environment. Governments must mandate laws to force their people to reduce their usage. As it was seen during the 2002 California energy crises, the state took action by initiating rolling blackouts to rheostat with individual reluctance. Another option being utilized is the use of new design processes to rely on low energy usage. Products that are energy efficient are promoted by government incentives or have a lower over all cost of operation (Reinders et al., 2013). The demand of energy efficient products is insignificant due to the investment's initial high cost.

1.3 STATE OF OUR SOCIETY

Social issues are society's perception of people's personal lives. Social issues directly or indirectly affect a person or many members of their society. Social problems range from poverty to racism that creates obstacles for people to obtain necessities of life. Social effects concerning products are not profoundly understood or studied. Products may be beneficial or hazardous to an individual's surrounding environment, heath, and culture.

1.3.1 SOCIAL: THE NEEDS OF MANY

The social needs of humanity can be classified from basic to complex needs. This may include acquiring food, clothing, water, security, and shelter in order to seek a healthy and

fulfilling life. Maslow developed a basic hierarchy of needs that are essential to human life (Peiró, 2006). The most important desires that must be met first are privatively physiological. The human body cannot function properly without physical requirements essential for human survival. The next level of needs according to Maslow, describe safety and security. This may include personal or financial security, health, and well-being. The third level of needs include love and belonging, i.e. friendships, intimacy and family. The last level consists of receiving respect and value from others, finally reaching self-actualization and self-transcendence. Maslow explains a generic inclination people have in order to obtain happiness in a society. In order to solve social problems one must fulfill social needs.

1.3.2 SOCIAL: PROBLEMS OF MANY

It is a moral obligation and a social responsibility not to hinder other vital needs. Nevertheless, the physiological needs of numerous individuals are being threatened every day by the aspirations of a few. Industry provides product accessible to billions of individuals around the world yet consequently, negatively affecting societies. This is done partly through the production of products in which create pollution, waste, deforestation, and other negative factors. Historically, nature provided the basic needs. The deployment of industry has contaminated these resources and is presently considered hazards to life. Product design must include the ideology to provide needs without hindering other essentials of life.

Many individuals across the world do not have access to their physiological needs of life. One billion individuals lack access to clean water (Kaplan, n.d.). One out seven individuals in the world does not receive an adequate amount of nourishment (Bowling, 1995). It is estimated

that two hundred million people are considered homeless (Van den Bergh et al., 2011). This statistic does not include semi-permanent homes such as vehicles, tents, sheds, or abandoned buildings. Sickness and death are a part of life. However, many of these deadly illnesses are preventable and environmentally driven. Pollution is a large global killer, affecting over 100 million people each year. Environmental pollution is a large social concern all around the world. Children make up ten percent of the world population while being affected by forty percent of global diseases (Masset, 2011). Three million children under the age of five die annually from environmental factors produced by pollution (McKiernan, Houchins, & Mattes, 2008).

1.3.3 Social: Solutions for the Masses

The essentials of society must be addressed to allow access and opportunities for individuals to met fundamental needs. The best indirect way to bring change is through products, for they can provide accessibility to rudimentary necessities, such as water and food. Also, product manufacturing and delivery chains can produce jobs and the means for individuals to obtain these indispensable products. Redesigned products can be the first and simplest step in improving lives around the world.

1.4 State of the Economy

Businesses are the largest and most powerful global influence. Single companies exceed the wealth of many governments. Commerce is vital to society for it is the largest employer and the major source of technological innovation. Incidentally, manufacturers are the agent that causes much of the damage to our environments and societies. Industries have an active

influence in all areas such as government policies, products for customers, environmental impacts, and social influence.

1.4.1 ECONOMICS: ROLE

Economics influences all aspects of life and society. It is equally categorized among environmental and social concerns. Nobel Laure states, "The propose of business is to obtain profits." While Milton Friedmans, "Argues the purpose of business is to create and keep customers." (Yilmazer & Schrank, 2006). The primary function of business is to provide daily equipment, products, and buildings. Businesses provide employment to the masses simultaneously creating wealth for investors. Economics are not directly responsible for environmental devastation or social breakdowns. Although, economics can be considered as a tool, allowing societies to grow in size and gain access to objects. An example of business's influence would be the direct correlation between poverty and global economy. Economies strength has a similar correlation with environmental degradation. For example, a lucrative economy thrives on masses exchanging money, so that more consumption can lead to more production, and hence more pollution. Hence, industries have a large impact on environmental and social problems by either ignoring or nurturing these elements.

Conglomerates have the ability to resolve problems presented to humanity by their economic gain. Subsequently corporations are the driving factor in the massive production of pollution and over use of natural resources. Commerce is a vital tool in creating a sustainable future providing ecological products to billions of individuals. We must first change the

business's selfish actions and incorporate human necessities and environmental protection into product designs.

1.4.2 ECONOMIC: INFLUENCE

Economic health is an important aspect of today's society. Financial evaluation has a significant role in global sustainability. The status quo stipulates flourishing economies equates to a healthy society while allocating resources for the protection of the environment. This scenario's downfall occurs in a weak economy, since the primary focus shifts from society and planet's security to economic salvation. The basic business premise is to provide goods to the individuals that desire them. An example can be portrayed from a simple business transaction between a farmer trading fruits with a rancher for meat. Hence, the intended purpose for economics was to give the ability to obtain and sell products and not destroy the world for greed.

1.5 Current Design Process

In order to create a new profitable product that can be sold, a variety of different checks and balances are required. In the process of creating a product, a designer must generate ideas through the combination of art, science, and technology. Product design procedures are plentiful, focusing on various aspects of different development. The majority of design processes follow a basic guideline that is categorized into three sections: Analysis, Concept, and Synthesis.

1.5.1 LIMITATIONS

Usually, designers utilize a guide for product development. An actionable guide is nonexistent in discovering, classifying, documenting, and applying contextual information in the application of sustainability in product design. The current sustainable design strategies state unclear suggestions and methodologies on products development. Figure 1 depicts a design process in its primitive mentality.

The basic design flow starts by stating a problem. Second, the first generation of ideas is accompanied by various analyses leading to the appraisal and elimination for its optimization. A design process allows a continuous evaluation loop to ensure all requirements are met to create a final product. The current design guideline systematically analyzes and evaluates ideas multiple times before a final proposal is developed.

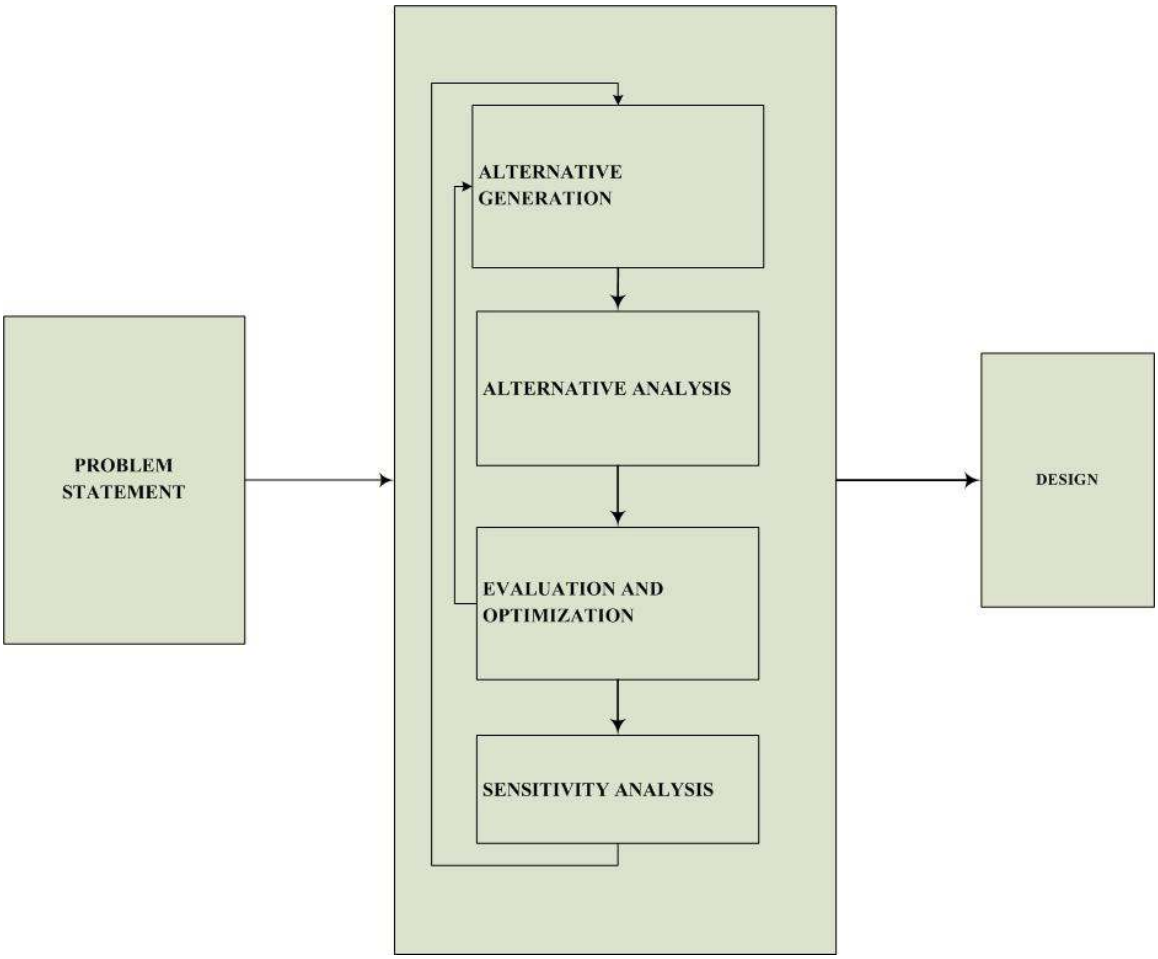

Figure 1: Current Design Process (Hara 2007)

Various design options are similar in their approach, procedure, and expected results. The existing sustainable design models are the following: Platform Driven Product Development, Delft Innovation Model, TRIZ, Technology Road Mapping, Design and Styling, Risk Diagnosing Methodology, and Quality Function Deployment (Cross, 2000). The flaws within the current models are nonspecific, unapproachable, and inapplicable for individuals in every day life. Sustainable product developmental steps and proven detailed guides do not exist for the common user. Engineers and designers possess skills and tools to design profitability verses pragmatic frugal innovation. Current design processes are limited to well-funded

organized institutions making it worldly inapplicable.

1.6 Sustainability

At the United Nations Conference of Environment and Development in 1987, Brundtland, coined as the, “Sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs", (Mathaisel et al., 2013). Sustainable design is creating tangible objects to comply with the social, economic, and ecological principles. The sustainable design’s intent is to, "Eliminate negative environmental impact completely through skillful, sensitive design", (Reinders et al., 2013). All life cycle stages must consider environmental, social, and economic aspects, ideally for a designer to design sustainability. A sustainable product strives to have the lowest possible environmental impact while offering opportunities for individuals in various necessities in life and financial benefits.

Sustainable projects are meaningful innovations that can shift a corporation’s behavior while being environmentally cautious. Elkington developed a powerful tool in depicting the entwined relationship amid global concerns by visually representing, The Three Pillars of Sustainability, also known as, The Triple Bottom Line, as seen in Figure 2 (Mathaisel et al., 2013). The model equally entails an economic, social, and environmental solution by symbolically representing them as pillars upholding sustainability. Furthermore, if any one of the pillars collapses, the entire system disintegrates. The three pillars of sustainability illustrates a strong connection between many issues seen today not limited to, poverty, equity,

environmental quality, safety, population, control, and many other global disputes.

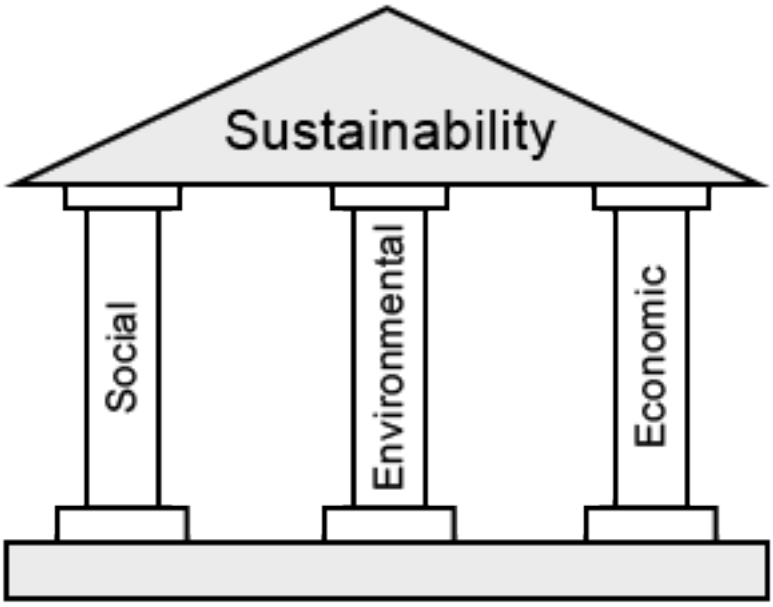

Figure 2: Three Pillars of Sustainability (Fiskel 2009)

1.6.1 LIMITATIONS:

Current solutions for solving major problems in design are dedicated towards a single pillar at a time, rather than a whole. Programs and agencies devote their focus towards single pillar solutions for worldly problems. For example, the United Nations Environmental Programmed (UNEP) was created to place emphasis on the environmental problems (McNamara & Caulfield, 2011). The World Trade Organization (WTO) concentrates on economic growth, while the Organization of Economic Cooperation and Development (OECD) promotes social health. Even though various organizations and societies exist to devote aid amongst all three pillars, the majority of resources are spent focusing on the economic mainstay. Utilizing Elkington illustration, this causes entire infrastructure shifts, generating a jugglers balancing act.

Evidently, a new approachable tactic is needed in utilizing the three pillars model effectively, addressing these problems simultaneously.

To generate an intended solution at solving problems, employing the three pillars of sustainability, a constant challenge remains amongst technological industries (Basurko & Mesbahi, 2012). The three pillars are required to be appreciated and considered equally, no more than another. Distinctively, plastic is a prime example of a product that is not considered sustainable. In a sense plastic, predominantly assists the economic pillar due to its inexpensive manufacturing properties and universal demand. Even though plastic also has a functional contribution to society since it is capable of protecting food, medicine, and other sanitized essentials from bacteria and a variety of contaminants (Knoblauch, 2009). Plastic falls short to be completely sustainable in lieu of its destructive environmental effects. Plastic pollution has been publicized to be devastating to animal life for it's cause of excess volume in landfills (Knoblauch, 2009). Plastic is one of many products that is innovative and has altered life on Earth. Hence, it fails to respect all three pillars to be considered sustainable.

In private and public forums, sustainability design is a circulated popular term. Sustainability is becoming critical to the industry environment for it is to recognize how important the environmental responsibility has on the industries long-term success. Sustainable products and processes give competitive advantage by reducing cost in various aspects and attracting new customers. Sustainable design reduces the steep end costs of environmental improvement projects needed to offset current product effects.

The goals for designing for sustainability include but are not limited to the following:

- High Economic Potential
- High Efficient of Raw Materials to Products
- Energy Efficient
- Safe for Environment and People
- Reduction of Pollutants

1.8 Life Cycle Assessment

A systematic approach must be taken to evaluate environmental, economic, and social assessment in a product's full life cycle. There are many different names, tools, guidelines, and methodologies to understand the sustainability of a product or service. Life cycle rational is a necessity of any comprehensive sustainability assessment. A life cycle assessment can be used as an objective technical tool to evaluate consequences of a product, production, process, packaging, or activity. A life cycle assessment procedure is not a singular process, rather information from any of the three components that can complement information from the other two.

1.8.1 Environmental Assessments

Environmental Life Cycle Assessment (E-LCA) is a methodological tool used to access the environmental activities consequences (Reinout Heijungs, Gjalt Huppes, & Jeroen B. Guinée, n.d.). E-LCA is a general tool covering all environmental interactions such as resources, energy,

and emissions arising during entire product life. The International Organization for Standardization (ISO) describes steps for executing a proper LCA, a product's assessment utilizing ISO 14040 standards, (Battle Frankline, 1993). LCA is the compiling and evaluation of input and outputs of a product. Inputs are raw resources while outputs are the effects on air, soil, water, and land use. E-LCA may also be used to evaluate alternative options and products that accomplish the same solution for a particular need. E-LCA can describe and evaluate every possible detail, directly or indirectly effecting the environment.

1.8.2 COST ANALYSIS

Life Cycle Cost Analysis (LCCA) methodology is the process of economic analysis required to assess the total cost of a product. These include internal and external costs: installation, operation, maintenance, conversion, and decommission of a product.

1.8.3 SOCIAL LIFE CYCLE ASSESSMENT

The goal of a Social Life Cycle Assessment (S-LCA) is the improvement of social conditions throughout product's life cycle. The human welfare is a concept that has been long debated and conceptually utilized in defining and articulating identification for the basic essentials necessary for human preservation. The most common social indicators are life quality, living standards, and human development. Quantifying these utilized markers, welfare, life satisfaction, basic human needs fulfillment, human development, utility, and happiness.

1.8.4 LCA LIMITATIONS

Life Cycle Assessments are utilized to quantify a variety of various aspects within a specific area in production. LCA currently are not standard, meaning there does not exist a set of goals that must be fulfilled by all. LCA allow researches to understand the effects their product has on any one of the three aspects of sustainability. This allows for modifications and adjustments if desired not a clear approved or rejected design. LCAs can be adjusted to focus on areas of concern or ignore these areas.

1.9 Problem Statement

The central objective of this dissertation is to investigate frugal innovation. This will assist designers in evaluating and understanding the value of frugally innovated products through the integration of environmental assessments, cost assessments, and social assessments. Neither an understanding of why frugal innovation occurs, an institutionalized methodology to produce them, nor tools to analyze successful frugal innovations have been developed. This dissertation is meant to set the stage to prove whether baseline understandings of frugal innovations are truly sustainable. The research will evaluate current frugal innovations to determine frugal innovation theories are correct and to what extent frugal innovation helps each pillar, e.g. separately and collectively. This work is novel for there does not exist prior work dedicated to analyzing and applying frugal innovation to sustainable assessments. This dissertation will take a glimps into the development of frugal innovations in India. This dissertation will discuss the current research and analysis of how individuals innovate in India and an effort of translating frugal innovation into a practical design process. Along with understanding the sustainability of frugal

innovations a model-based design with the combination of three methodologies, social, environmental, and economic life cycle assessments, used in assessing sustainability will be advocated. The model-based design will give the first step in creating a methodology in enlightening individuals in all areas the benefits and application of frugal innovation.

CHAPTER 2: FRUGAL INNOVATION

Local companies in emerging nations like China and India are increasingly developing innovative ideas and products. Many have flourished by developing products that offer superior value at lower cost. Frugal innovation is considered a new approach in evolving ideas that address contextual factors, constraints, and local demands, (Bhatti, n.d.). Its distinction is derived from the essential means and ends that utilizes limitations in resources and advantageously uses them. Restraints in resources are limitations in materials, labor, financial, stable infrastructure, or combined. Successful frugal innovations are low cost and even at times out perform, if not compete with alternative products, (Kirsten Bound and Ian Thornton, 2012).

Many individuals may see frugal innovations as cheap and low-technical alternatives. However, the ideology is based on challenging conventional low quality. Frugal innovations strive to make things better, not just less inexpensive. Frugal innovations are not merely products but services as well. The base of a frugally innovated product is not to de-feature it but to remodel the entire product and manufacturing process. Another notion of frugal innovation is that it is not low-tech but rather may be utilized with premier technology.

2.1 Frugal Innovation: Low Cost but High Performance

Frugal innovation understands that to increase performance does not mean to increase the complexity, (Tiwari & Cornelius, n.d.). This concept can be seen as an effective way to solve a specific problem. A prime example of this notion is the jaipur foot; the jaipur foot was developed as an alternative prosthetic leg because of a lack of an affordable one available in

India. The only prosthetic limbs available cost upward of $10,000, which was too expensive for any low to middle class individual to obtain. The jaipur foot was named one of the best inventions in the world in 2009 by Time magazine because it was accessible to millions, (Berger Roland, 2013). The jaipur foot costs under $45 dollars, is made from rubber and wood, and looks like a real foot. The new prosthetic also improved movement compared to the available limbs at the time. The jaipur foot is durable and reliable. A person wearing it can sit, squat, walk on uneven road, and stand in water with out affecting the foot. Figure 3 correlates a cost decrease in product along with a cost decrease in process.

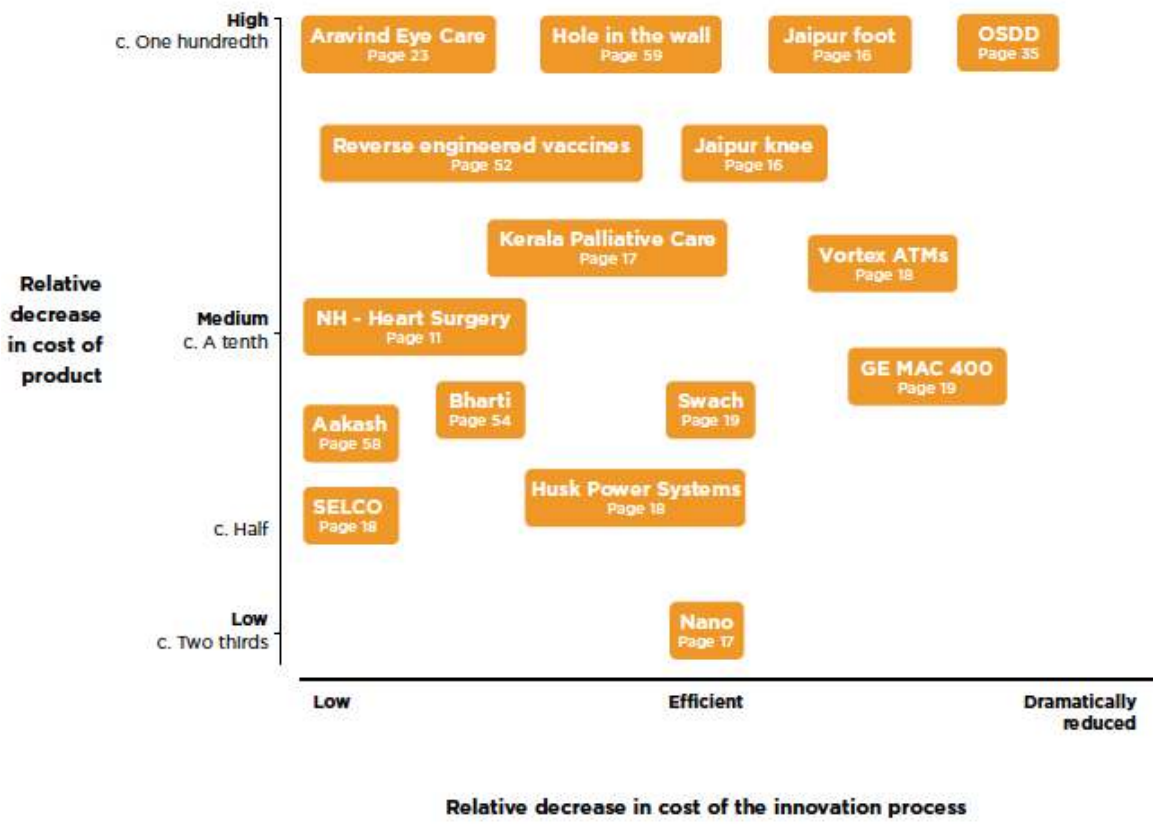

Figure 3: Frugal Innovation Cost of Product vs. Cost of Process (Zeschky 2011)

2.2 Frugal Innovation: Remodeling Not De-Featuring

Frugal innovations can be called innovations by not the product themselves but the methods on how the product was developed or the ways it was deployed to the public. Take for example, the Nano Tata, (Bhatti, n.d.), a low cost vehicle that was remodeled from the bottom up. The vehicle consists of fewer bolts, one mirror, new engine technology, light steering, and a completely new look inside and out compared to an average car. Frugal innovations solve the same problem but with a new method.

2.3 Frugal Innovation: Low Cost Not Low Tech

Frugal innovations are not all low-tech items but can contain the newest technology available. Technology is sometimes even required in ordered for the product to be competitive with current alternatives. For example, Tata Chemicals created water filters for India that cost less then 50% of traditional filters, (Bhatti Yasser, n.d.). The Swatch water filter cost $20 and operates with out electricity or running water, but can clean up to 3,000 liters of water. The Swatch looks simple and the cost is extremely low, but utilizes silver nano particles to remove contaminates.

2.4 Frugal Innovations: Where and When

Frugal innovation is not an idea that came about one day but is a concept that has been built on for years, (Bhatti Yasser, n.d.). Frugal innovations can be seen across India. This notion of solving a problem with what you have is essential for survival. Frugal innovations are being utilized all around the world as well, but today are mainly utilized in areas of extreme poverty

such as developing nations. Frugal innovation is not limited to developing nations that are plagued with poverty but seem to prosper in these environments. However, if properly understood it may be used in developed nations as well. Research into frugal innovations began in India, which is believed to be the birth of "jugaad" (to do without). The identification of the name might have been from India but individuals throughout history have understood limitations and used them as strengths. However, the current study of frugal innovation is about the global movement and growth of frugal innovation as described in Figure 4.

	1960s to 1980s	1980s to 2000s	2000s to 2010s	2010s onwards
Social movements	Appropriate technology	Sustainable development	Private sector-led development	Ethical capitalism?
Globalisation of science, technology and innovation	-Technology transfer from developed to developing world	-Growing distribution of technology design and production with the rise of the East Asian Tigers	-Increasingly networked global innovation system as multinationals explore new locations for R&D	-Interdependent, globally segmented innovation by multinationals. Two (or more) way flow of ideas
		-The Internet	-Cheap connectivity	-Widespread digital platforms for collaboration
Innovation management schools of thought	-Systems analysis	-Lean manufacturing -User-led innovation	-Open innovation -Design thinking -Frugal engineering	-Frugal innovation
Emerging economy markets	Peripheral	Emergent	Recognised - the fortune at the bottom of the pyramid	Towards the centre of gravity

Figure 4: Timeline of Innovation (Zeschky 2011)

A study conducted by Stuttgart, (Berger Roland, 2013), surveyed 60 managers who identified key characteristics and success factors along the frugal product value chain. The individuals suggested that frugal products are low-to-mid end products sold mainly to emerging markets. Functional, robust, user-friendly, affordable, and local define frugal innovation attributes, seen in Figure 5. Each attribute independently functional is a products performance rating, as being low-to-mid end. Robust refers to products that are easy to maintain. User-friendly products are simple and easy to use produces being evaluated as a simple or complex. The next attribute is affordability, which are products that are low priced and offer good value for the money; this is evaluated by low, medium or high price. The last quality is locality, which describes where the products are sold and manufactured, such as in an emerging market, low end establish markets, or high-end markets.

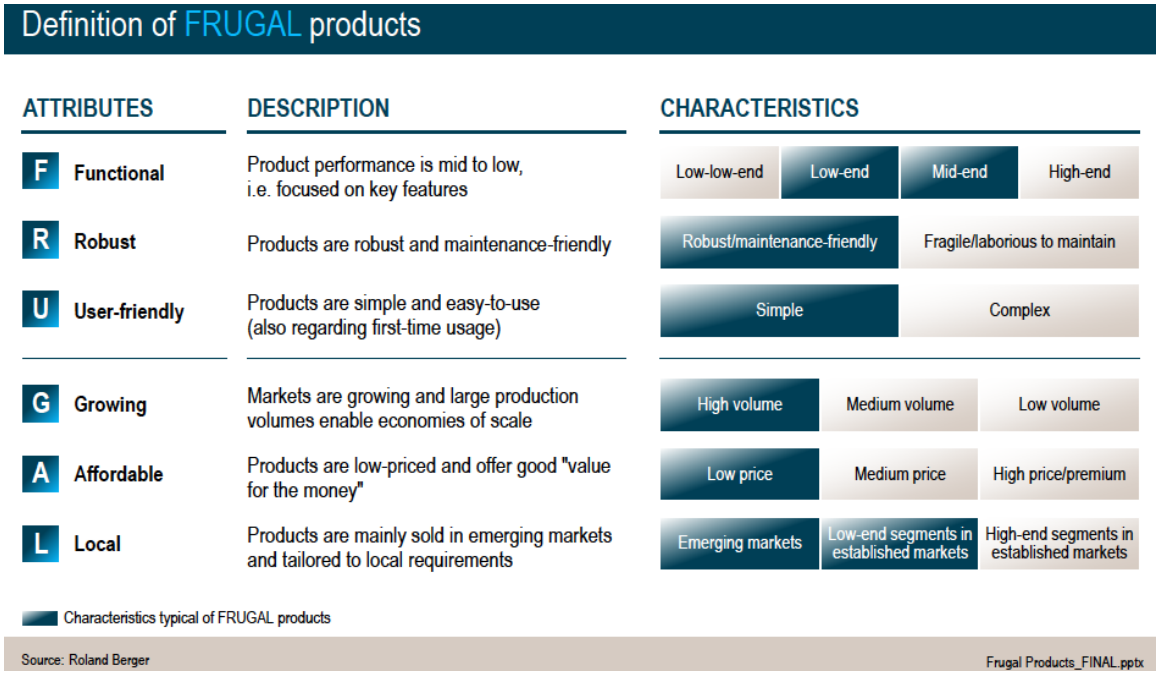

Figure 5: Attributes of Frugal Innovations (Berger 2013)

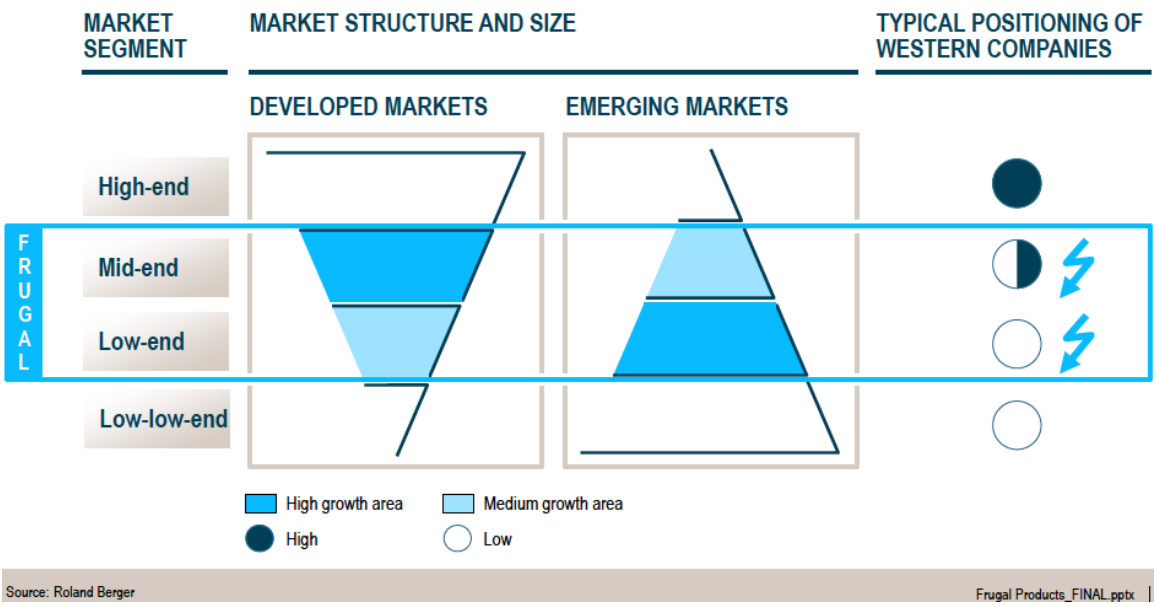

Figure 6: Frugal Market Segment (Berger 2013)

The Figure 6 reports western companies do not have a strong presence in low-to-mid market segments. However, the areas of low-to-mid end products are the highest growing segments of global engineered products. The growth of mid-range products is at 10 percent and low-end products are growing at 11%. The Figure 7 demonstrates the growth rates between high-end, mid-end, low-end and low-low-end products. The graph also shows potential growth of all segments by the year 2015.

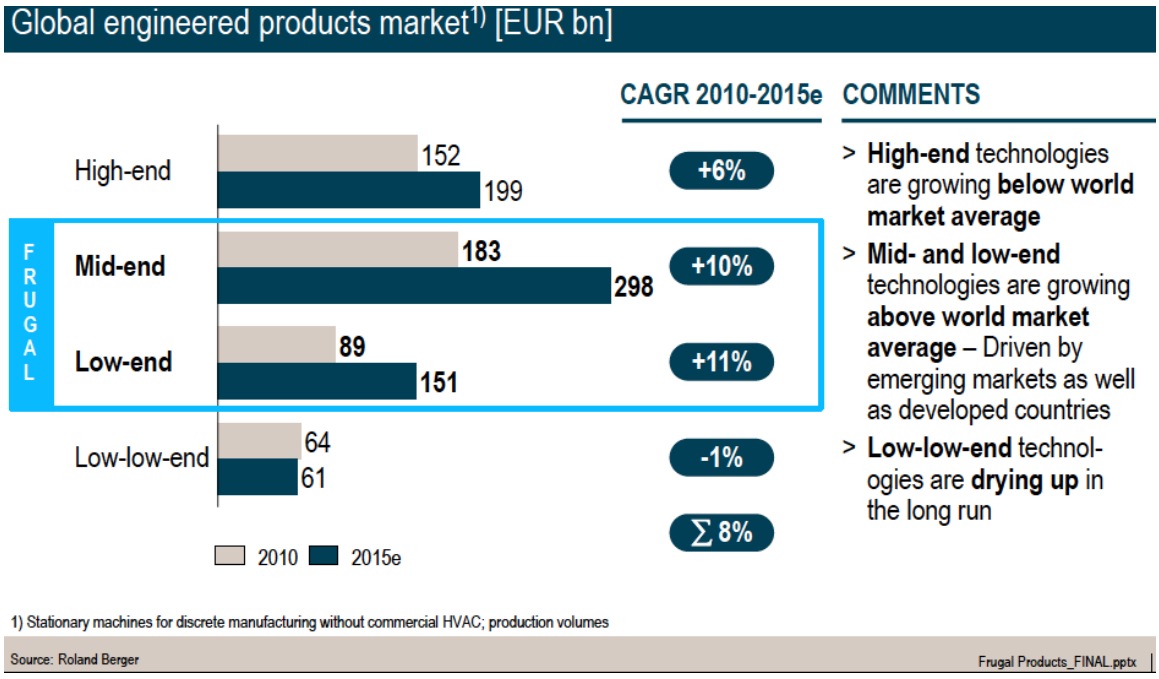

Figure 7: Global Engineered Products (Berger, 2013)

2.5 Frugal Innovation: Economics

Frugal innovations are utilized in markets where a large segment is aspiring to become middle class. Millions of individuals in India have grown out of poverty in the past years and have had a rapid growth of middle class people. The current middle class contains 50 million people but estimates show by 2025 the middle class will have 583 million people. Along with large numbers of costumers growing they are price sensitive but willing to try frugal innovations. The bottom of the economic pyramid still posses needs and wants as everyone else in the world. These needs are not luxury items but items to satisfy basic living necessities.

The fastest growing markets are developing and emerging economies that have a demand for low cost products. This large new segment will create a large demand for frugal innovations

that can meet expectations of being low cost and high quality. The middle class in Asia is growing in a profound rate, it is reported 10% spending is from middle class, however by 2030 will share 40%, (Minghua & Yongzhong, 2011). The main products being purchased are and will be affordable. The development of low cost products compared to current products will create new opportunities. Frugal innovations may be used in developing nations as well, for individuals or institutions that need or want good enough products to save money. This is a new frontier for the western market rather then selling the best, they will sell what is needed, and therefore, there exists rapidly growing segments desiring these products.

Frugal innovations help grow economies by allowing individuals to allocate money else where rather on expensive products. The question still remains, how much profit do frugal innovations create? Frugal innovations are considered to be the solution to current economic issues. Many frugal designs are developed to create large profits by selling products at razor thin profit margins but at high volume quantities. Amazon is a prime example of a company utilizing this type of business strategy. Amazon is a large online retailer with revenue around twenty one billion dollars but with a hundred million dollars in income; a margin of less half a percent profit, (Corsano, G et al., n.d.) This strategy keeps Amazon competitive and strong company by passing the savings onto its customers. Frugal innovations have a similar strategy, relying on razor thin profit margins to promote the product to extreme low-income populations.

2.6 Frugal Innovation: Social

Frugally innovated products proclaim to be designs to promote availability to the bottom levels of economic hierarchies. The fundamental framework of frugal innovation is established

on developing products that are customer influenced. This new concept utilizes the need of the customer by understanding that all individuals in any economic level have a need for basic necessities to survive. Frugal innovations give a broader group of individual's access to products that help their lives by being extremely low cost. Basic necessities range from individuals but necessities to survive are similar to all mankind. Such necessities include an adequate supply of clean water, nutrient rich foods, shelter for protection from the environment, and satisfying the need to be creative; either through education, the arts or exploration. These are considered the essential necessities for mankind to flourish. Frugal innovations are products that give people the means to have these necessities and luxury items.

People that utilize and appreciate frugal innovations are ones that live in extreme conditions. These conditions require a demand in low cost products, dealing with health, education, and energy. The rural population in India is 833 million and dispersed across a couple of million square miles. The low-income individuals do not have access to health care, clean water, adequate food, or sufficient living conditions. Necessity is the mother of invention. Hence, millions of Indians are looking not at their government for help but at each other to solve the problems of their society. The Indian Prime Minister Manmohan states that research should be directed to providing frugal solutions to our chronic problems of providing food, energy, and water security to our people in a more efficient way, (McKiernan et al., 2008).

Another need for frugal innovation is the rapid aging of societies and their need for health care. In the United Kingdom, by 2031, the number of 75-year-old individuals will double,

(Health, Crisis, & Parts, 2011). The anticipated changes in demographics will increase costs of health care and other services in order to keep up with the growth.

2.7 FI and the Environment

Frugal innovations are not described as an environmental friendly design. However, frugal products are designed to use a minimal amount of materials and energy. The utilization of less materials and energy reduces the product's environmental impact. These impacts range from reducing non-renewable energy, which in turn reduces atmospheric pollution. Frugal designs utilize materials that are abundant and recyclable thus bestowing a positive influence on the environment.

2.8 FI Examples

Frugal innovations are being utilized not only in developing countries but in developed nations as well. An example of frugal innovation can be observed in a unique electrocardiogram (ECG) machine that was developed to maximize the value but minimize nonessential costs directed towards the customers, (Bhatti, n.d.). Mass production techniques are applied to make numerous quantities of these economical machines in India, (Zeschky, Widenmayer, & Gassmann, 2011). This product is portable and durable, thus permitting access by individuals in rural areas. The device is not as sophisticated as larger western ECG machines, however, it accomplishes the same task, (Sharma & Iyer, 2012).

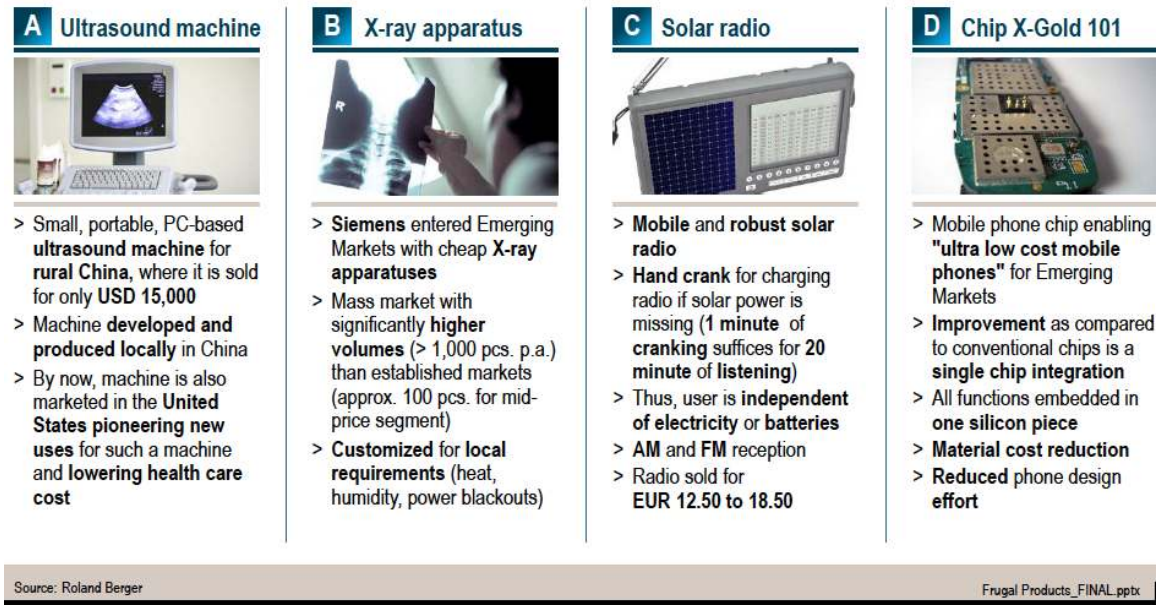

Figure 8: Examples of Frugal Innovations (Berger 2013)

CHAPTER 3: LIFE CYCLE ASSESSMENT

Life Cycle Assessments (LCA) are the evaluation of all environmental, social, and economic negative impacts, benefiting in decision-making processes towards more sustainable product through their life cycle, (M.Z. Hauschild, L.C. Dreyer, & A. Jørgensen, 2008). LCAs are sets of procedures that require inputs of products throughout the life of a product. LCAs assess the potential impacts of the product upon environmental, social, and economics.

3.1 Background of LCA

Product impact studies have been in practice for many years, (Miettinen & Hämäläinen, 1997). Companies such as Coca-Cola wanted to know the resources used and the environmental effects of making their product. Other companies have used LCAs to determine energy used in many of their products such as glass, plastic, phones, and steel. However, within the last two decades the Society of Environmental Toxicology and Chemistry (SETAC) and the United Nations Environmental Program (UNEP) have created many uses and methods of LCAs. The objective of UNEP and SETAC

- Enhance the global consensus and relevance of existing and emerging life cycle approaches and methodologies
- Facilitate the use of such approaches worldwide by encouraging life cycle thinking in decision-making for enterprises, public authorities and consumers
- Expand capability worldwide by applying and improving life cycle approaches

3.2 LCA: Design Process

The limiting factor in applying LCAs in a design process is determining the appropriate indicators. Designers have easy access to economic assessments through data of unit cost, cost of raw materials, manufacturing factors, labor, and delivery of products. A combination of social, economic and environmental indicators and data allows for the identification of a superior design and process.

The use of multiple assessments can create conflicting objectives to designers. Tradeoffs must be made to create a product that is optimal in cost, feasible, and beneficial for people without environmental consequences. This dissertation presents a systematic approach allowing evolutions in the design process. The application of the methodology will be demonstrated through the evaluation of frugally innovated products.

3.3 LCA: Environment

Environmental Life Cycle Assessment is a technique used to evaluate environmental aspects over the product's life. Established standards are ISO 14040 and 14044 and composed of four phases as a guideline to evaluate a product, Figure 9, (Battle Frankline, 1993).

- Goal and scope
- Inventory of resources, use, and emissions
- Impact assessment
- Interpretation

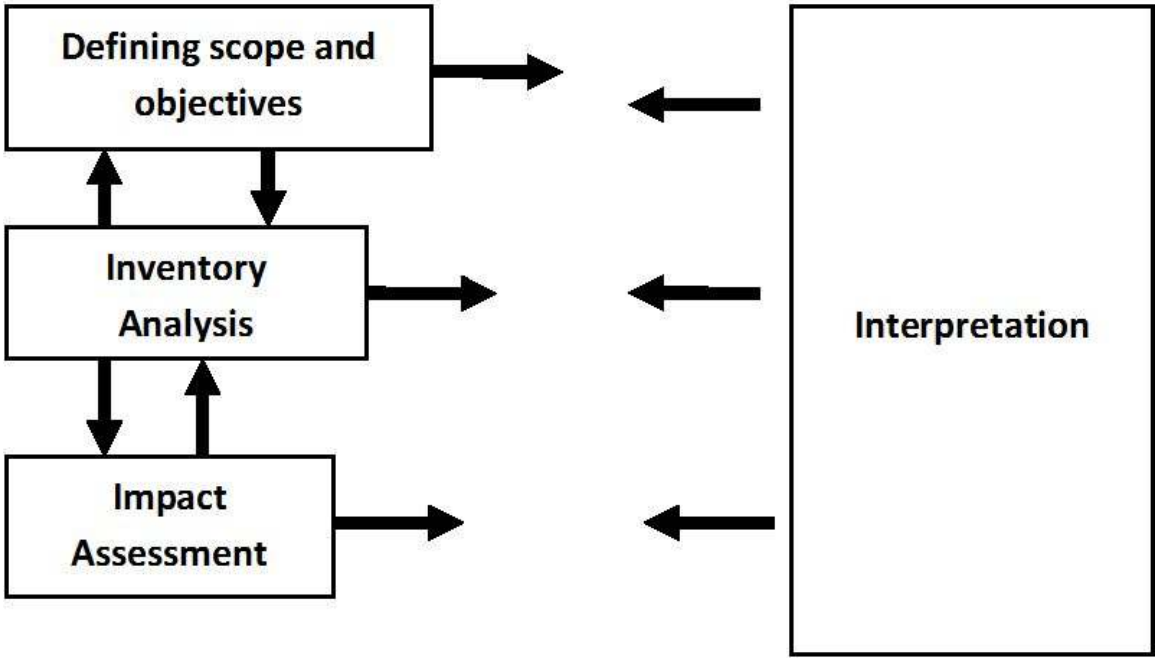

Figure 9: Guideline to Evaluate a Product (Klpffer, 2003)

The first phase of LCA is goal and scope; this defines the reason of the study. The step gives reasons of target group and product description to be evaluated. The evaluators will analyze and determine what they wish to accomplish. In this section, one must answer what is the purpose of the LCA and determine what decisions can be made from the results. Scope is the identification of the object and functional units and assigning parameters.

Once a goal and scope are completed the next step is inventory analysis. This step gathers all the data about what resources are used in the manufacturing of the product. The flow of materials such as mining of raw materials, manufacturing, transportation, distribution, use, and disposal of the product are tracked. Figure 10 describes a basic inventory analysis.

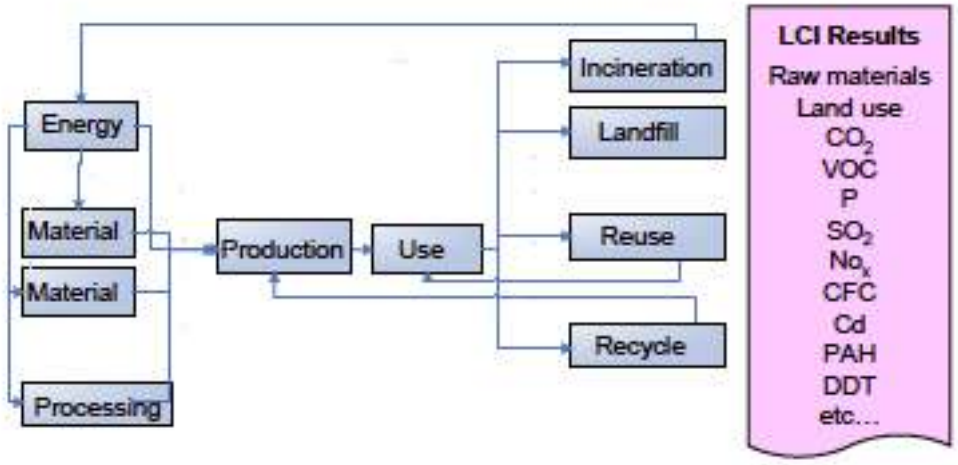

Figure 10: Inventory Analysis (Klpffer, 2003)

The third step is the impact assessment, which uses models to describe effects the product has on the environment. Figure 11 is an overall scheme of an environmental life cycle assessment. The impact assessment can be simplified into three points:

1. Calculation of potential contributions to various categories of impact.
2. Comparison of impact potential and resource consumptions with a common reference.
3. Weighting of the normalized of impacts and consumption to determine a scale for most to least important.

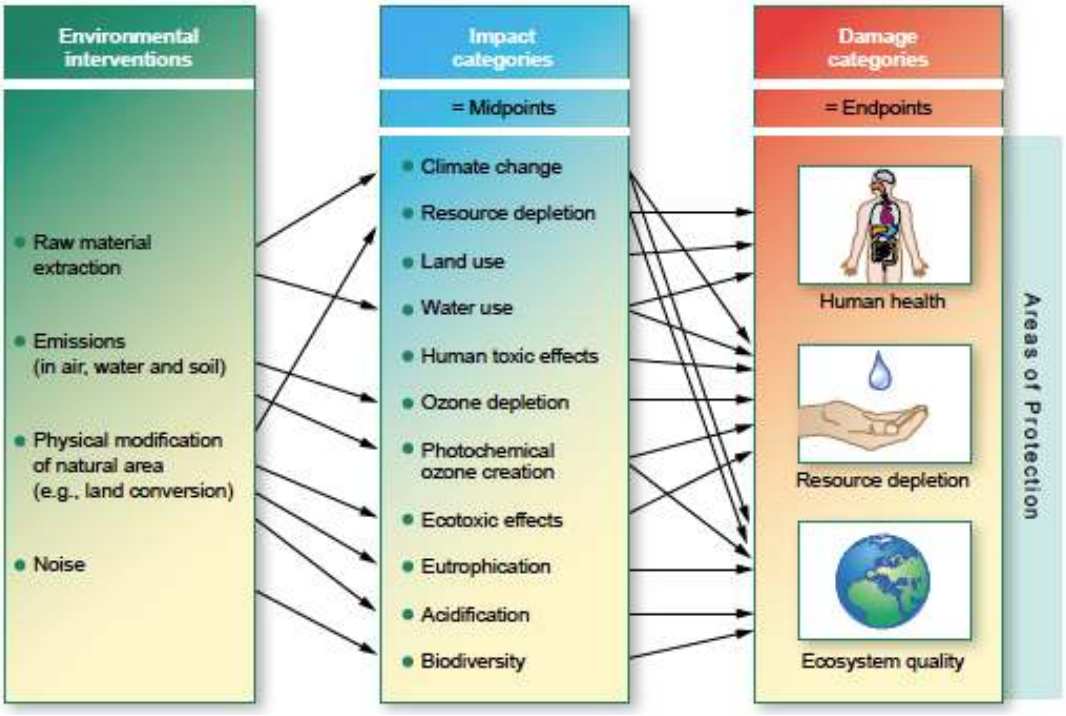

Figure 11: Environmental Life Cycle Assessment (Klpfeer, 2003)

3.4 Environmental Impact Categories:

The following is a list of the most common environmental impact categories:

1. Global Warming Potential
2. Energy Depletion
3. Eco Toxicity
4. Acidification Potential
5. Nitrification Potential
6. Ozone Depletion

3.4.1 Quantification of Global Warming Potential and Ozone depletion

Global warming potential is calculated by dividing the amount of emission by equivalency factor, Carbon dioxide, Equation 1, Table 1 reports common greenhouse gases and their equivalence to carbon dioxide, (Greenwood, 1961).

Equation 1: Carbon Dioxide Equivalency Factor (Klpffer,2013)

$$GWP_i = \frac{contribution\ to\ global\ warming\ \ from\ gas\ i\ over\ T\ \ years}{contribution\ to\ global\ warming\ \ from\ CO_2\ over\ T\ \ years}$$

Table 1 : Key Greenhouse Gases (Klpfeer,2013)

Designation or Name	Chemical formula	Lifetime (years)	100 yr GWP (SAR)	100 yr GWP (AR4)
Carbon dioxide	CO_2	Note [1]	1	1
Methane	CH_4	12 [2]	21	25
Nitrous oxide	N_2O	114	310	298

3.4.1.2 Ozone Depletion

The most common are CFCs, Halons, methyl bromide and HCFCs. Calculation of ozone depletion potential is shown in Equation 2.

Equation 2: Ozone Depletion Potential (Klpffer, 2013)

$$ODP_i = \frac{contribution\ to\ stratospheric\ ozone\ depletion\ \ from\ gas\ i}{contribution\ to\ stratospheric\ ozone\ depletion\ \ from\ CFC11}$$

The last is the interpretation of the model. This is used to check information from the results of the LCA. This should give a set of conclusions and recommendations. Interpretation will include sensitivity and limitations of the product.

3.5 LCA: Economic

Using Life Cycle Cost Analysis (LCCA) we can determine the total cost of the product over the entire life cycle of a product. The use of LCCA allows designers to evaluate alternatives and trade offs to assist consumers. The methodology of life cycle assessment are: first to determine the time for each cost element, second estimate a value for each element, third is to calculate net present value of each element for a period of time, then last calculate LCCA by adding all cost elements at every year to analyze the results.

An internal cost is what the manufacture is responsible for paying over a period of time. Internal cost may be identified as initial cost and operation and maintenance cost. Initial cost encompasses the cost of design and development, investment such as equipment cost and cost of installation or erection of establishments such as buildings or manufacturing equipment. The operation and maintenance costs are labor cost, energy cost, and raw material costs. Life cycle cost assessment incorporates other notions of cost, such as conventional costs, external costs, and social cost. Figure 12 shows a scope of various cost assessments.

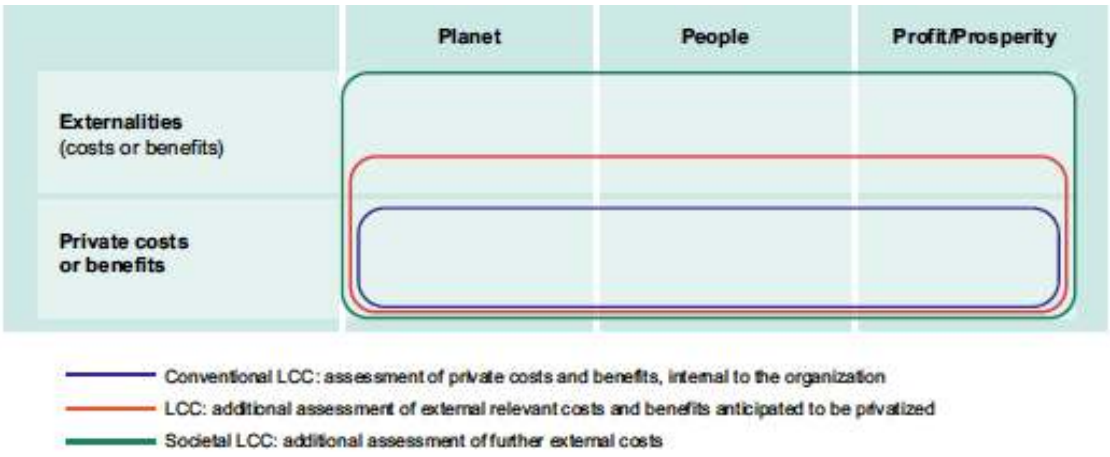

Figure 12: Various Life Cycle Cost Analysis (Miettinen, 1997)

To determine the cost and benefits assessment, a four-phase process is used:

- Define a goal, scope and functional unit
- Inventory costs
- Aggregate costs by cost categories
- Interpret results

The process of Life cycle cost assessment is similar to the guidelines and methodology of Life cycle assessment of the environment.

3.6 LCA: Social

S-LCA may be conducted on any product; S-LCA is a technique that helps inform incremental improvements or evaluations for sustainable consumption and sustainable living. S-LCA provides information on social aspects for decision-making, instigating dialogue on the social aspects of production and consumption, in the prospect to improve performance of organizations, and ultimately the well-being of stakeholders. Stakeholders are categorized as

workers, consumer, local community, and society, described in Figure 13.

However, the various types of social impacts are dependent on the product, so it is highly suggested that the social assessment of the product be carried out on product category basis. The guideline and application of the social life cycle assessment is similar to the previous assessment methodologies above.

- Goal and Scope
- Inventory
- Impact Assessment
- Interpret Results

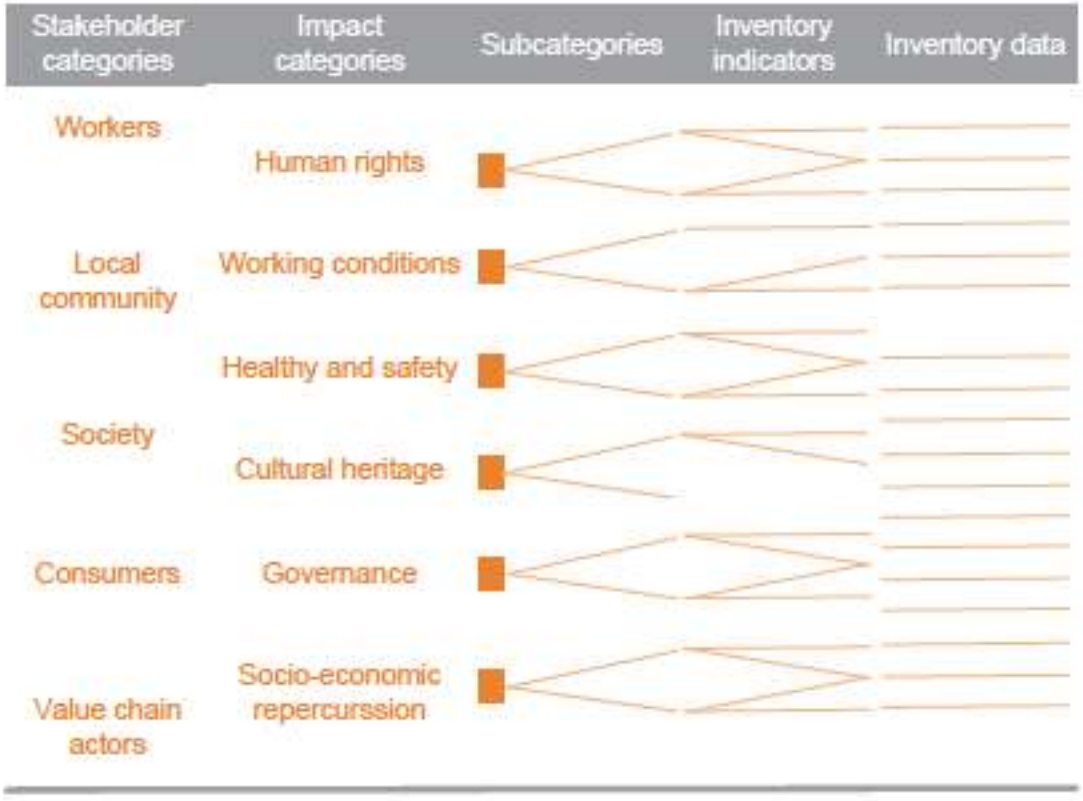

Figure 13: Social Life Cycle Assessment (Battle, 1993)

3.7 LCA: Product Comparison

Life cycle assessments allow for a broad comparison of the effects of similar products on sustainably. Figure 14 shows an example of a life cycle assessment of total sustainability. However, data to complete the three types of assessments must be gathered from suppliers, customers, and manufactures. This data will help evaluate the productive lifetime, length of operational time, and give insight on design calculations. The amount of data needed is unknown. As well as the specific data are unknown aspects because life cycle assessments are not standardized.

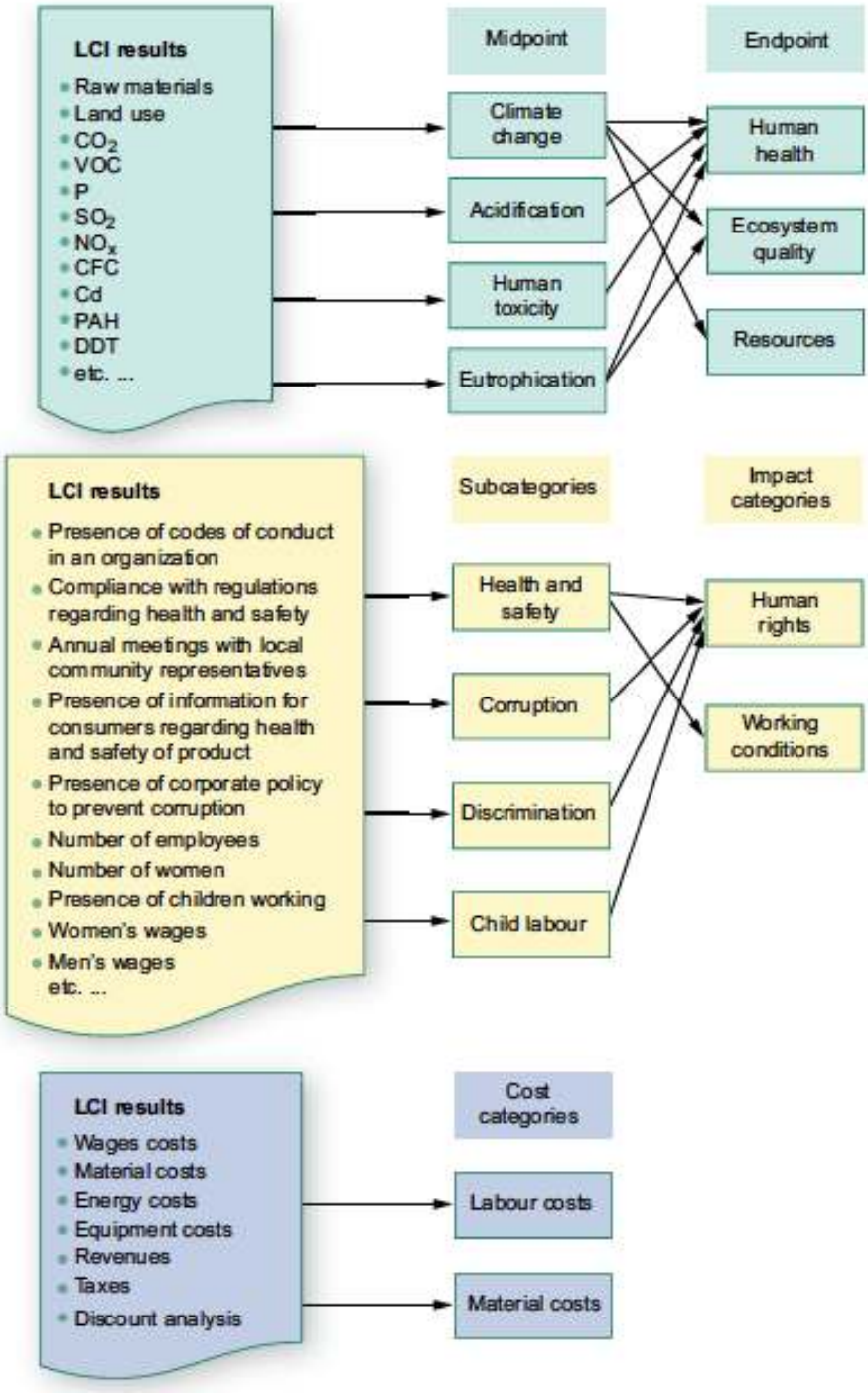

Figure 14: Sustainable Life Cycle Assement (Battle, 1993)

CHAPTER 4: LITERATURE REVIEW

The main objective of the present work is to study the effects and methods of both conventional design processes and sustainable design processes. The focus is aimed towards gaining insight into the systematic approaches of design and applications. This material has been studied recently to a certain extent to understand impacts of the three pillars. However, design for sustainability is expected to be in its infancy stage of development thereby the research is somewhat limited. Furthermore, conventional design process is a vague term that can be studied in multiple layers of development or multiple areas of designs. This chapter will discuss some of the previous studies both on product design and development and the effects of this process has on economic, social, and environmental pillars. Also, a review of studies that look into guidelines on what consists of sustainability and product designs will be discussed regarding the techniques, characterization of methods, and overall understanding of designing different viewpoints.

4.1 Conventional Design of products

Sharma conducted several studies on product development where a comparison of resource-constrained and conventional product development where made, (Sharma & Iyer, 2012). The first topic discussed was the framework of conventional design. The design process, she discusses enables individuals or companies to gain significant competitive advantages with radical innovations. Consequently, companies spend a significant amount of revenue towards Research and Development to find the next big thing. The motivations are ruled by the notion that new products must fit the existing mold of market conditions and demand. The second

aspect discussed, was the basic framework of design. Radical innovations come with a customer willingness to pay higher prices for new and exciting innovations as compared to incremental innovative designs. The focus of designs is at radical innovations that are valued highly by costumers and assigned high prices with acceptance and willingness from the consumer to pay the extra cost.

The dogma of conventional innovation is guided by the wants of people with an assumption there exists an endless raw material supply. Sharma also recognized that in conventional product development physical infrastructure does not play a special role, in fact it is assumed to be available. Conventional design process does not pay special attention to various institutions necessary for success. It is assumed that economic institutions and other factors needed for commercialization of innovation are available. In this article, Sharma develops a system displaying differences between conventional and resource constrained product development. The comparison is between eight categories; corporate objectives, corporate resources, prices, environment, infrastructure, government, supply chain, and customer markets. Each category has extreme differences with conventional design thought process having objectives heavily favoring competitive advantage through radical innovations. Resources are created through dedicated funding. The customers consist of segments willing to pay for the high prices along with government policy that supports incentives and a well-developed market institution. Resource constraint design is the polar opposite of conventional design with the notion that resources are limited, rids the notion of radical innovation high prices, and has little government assistance and works in infrastructures that are unrealizable. Sharma's paper outlines the differences between design processes with an outside look of needs to design.

This paper states there exists a need for change of current design processes to a process that takes into account environmental limitations. This paper provides an understanding of conventional design process but lacks a method on how to come about this new process.

Ulrich developed a methodology on conventional engineering design and development, (Ulrich & Eppinger, 2000). This particular noteworthy study was focused on the direct application of product design and development and characterizes the product development, motivation factors, and many challenges of development. Ulrich defines the core functions of marketing, design, and manufacturing with integrative methods intended to facilitate problem solving and decision making for conventional designing. He states there exists a standard development process that will work for every company and the milestones for overall development.

The paper states six generic product development processes consisting of planning, concept development, systems level design, detail design, testing, refining, and production ramp up. The amount of detail given for all levels is extensive, so for this dissertation I will focus on Ulrich's ideas on concept and design. This paper suggests that the concept stage is where the needs of the target market are identified, alternative product concepts are generated then evaluated, and one or more concepts are selected for further development along with testing. The concept stage brings an understanding of form, function, and features. These qualities are determined by the analysis of competitors' products and economic justifications.

Concept stage data is considered extremely important in Ulrich's study. The data obtained for product conception is raw information from customers and their needs. In this stage, Ulrich believes that establishing the relative importance of these needs is necessary, for not everything can be accomplished in one product. The concept stage is focused on the customer's wants and hidden needs as well, but may be considered expectable exemptions if cost is not fulfilled. Conventional product designs try to understand what the costumer wants and with the willingness for them to pay a higher price for additional features.

Ulrich utilized multi-attribute decision-making matrixes to give designers assistance in determining characteristics for products. The matrix needs to be practical and some needs cannot be easily translated into quantifiable metrics such as a product's ability of instilling pride; but how can pride be quantified. Rather than including this in the matrices they dismiss it and evaluate these aspects that cannot be quantified through a panel of designers suggestions.

Ulrich gives detailed explanations on how the process of designing is catered to customer wants and economic success with no implication on social or environmental impacts. The design process utilizes surveys and suggestions from the targeted group but with designers using intuition and trial and error to understand what is the true motivational factor for customer success. The conventional design process is guided by the idea of what costumers want and influenced highly by the reduction of cost in the manufacturing stage.

Several texts describe conventional product design methods, (Bralla, 1986),(Belliveau, Griffin, & Somermeyer, 2002),(Ryu, 2012),(Hara, 2007). These methods recognize the need for

early stage design also named as the "fuzzy front end" process, (Belliveau et al., 2002), this also provides direction on the understanding of opportunity, (Hara, 2007), and gives guidance on how to clarify a task, (Ryu, 2012). Belliveau expands on the notion of the importance of the fuzzy front-end importance in designing. He describes design into three separate but equally important areas: the fuzzy front end, new product development, and commercialization. He provides methods, tools and techniques for managing the fuzzy front end in conventional design processes.

Belliveau states there is a lack of research in the fuzzy front-end area and that this is a promising trail for innovative designing. He limits his studies on examples and explanation of fuzzy front end stating it is an unpredictable, very experimental, and often chaotic process. He also states that the cost of this process is uncertain but needs plenty of funding to proceed. The concept of fuzzy front-end is to gather information and ideas to solve problems in the product development stages. The importance of this paper was to understand that research and understand beginning stage development is vague and has no strict guidelines. The process of creating and problems solving with products is an unknown path that needs assistance to continue with product design.

Hara dives into the imagination of design with her study of Designing Design Research, (Hara, 2007). Hara utilized many different techniques for designing and to understand the underlying notion of a great design. She begins by looking at redesigns of current products by simply adding improvements or applying radical thinking to the design purpose. Some of these products are successful yet the majority are considered not as efficient as the original, but are

considered unique ideas that may be utilized in other product design. Hara then describes how designers can utilize the world around them for ideas and inspiration. An example given was Leonardo Di Vinci's observation of birds to understand the concept of flight. Hara believes that nature inspires the creativity thought process in the human mind. Her studies provide insight on how to spark creative mind thinking in an individual. Hara's study gives an insight on how people become inspired.

Ryu describes in his research how technology is essential in the process of new product design, (Ryu, 2012). He suggests that there exists a hierarchy for products that utilize technology in design and manufacturing. The use of technology in a design is very complex in his finding, for the designer must decide on what types of technology is best for the product, how to incorporate the technology in a product, and finally he tries to understand when technology is inapplicable. He suggests in his study that technology is important to design, but to what extent is unclear, for there exists a need of a proper infrastructure for upgrades and maintenance. This idea that technology has limitations can reduce the reliability and quality for product success. Ryu explores the importance of technology and reliability in the paper as being essential to product design. This aspect is necessary to understand if one intends to produce products for individuals without a national infrastructure capable for reliable highly technical products.

Two books about design process that are relevant are written by Meier titled Product Design and Engineering, (*Meier, n.d.*) and another written by Mileta titled Product Realization, (Tomovic & Wang, 2009). These books are important to this dissertation since they elaborate on how the conventional product design is being utilized all over the world and the focus points of

product development. These books review important points in a product life cycle dogma: conception to manufacturing and finally disposal. They also point out desired parameters and the use of supplemented constraints during product development. The factor of cost is a main driving factor in decision-making and at times may override any other factor such as customer need. Analysis of products is essential to understand how to design products to maximize profits. The majority of both texts is to understand that design is important but must provide profit for the manufactures.

Bralla provides insight on the understanding of design economics through a guideline, (Bralla, 1986). This research describes the responsibilities of designers to engineer products that have qualities such as; functionality, durability, appearance, and most importantly, low cost. This study looks at detailed cost factors related to conventional designing. The cost for a design comes from materials used in the production to the delivery of the product. The study elaborates on direct labor cost involved such as the manufacturing process and the salaries of designers. There also exists indirect labor cost, utilities, capital costs, and other expected cost for an entire process of designing. Bralla then explains about principles of design for economical production, giving a good insight on designing for the lowest cost product. Utilizing simplified processes, standard materials, standard design, pre accessible materials, and collaborating across manufacturing compartments, one can reduce costs. Bralla gives much insight on how to design on a budget even though his research is directed towards conventional design. His strategies may be applied for frugal innovations as well.

The literature reviewed over the concept from a conventional design mindset is plentiful.

It ranges from processes to products and case studies, but with the main notice that design is not a true science and imagination is required. The other aspects understood from the literature were that design is based on consumer needs but without much guidance from the costumers, beyond satisfactory surveys. The last important element from this review is that conventional design. It is directed by cost factors with no social impacts influence, environmental protection, or limitations. This review was meant to give an understanding of what methods and ideas are being used to create products in developed nations.

4.2 Life Cycle Assessments: SOCIAL

Social life cycle assessment is considered to be in its infancy compared to environmental life cycle assessment, (Hauschild, Dreyer, & Jørgensen, 2008). Social Life Cycle Assessment (S-LCA) is defined as the social impacts of all products life cycle, (M.Z. Hauschild et al., 2008). Nazarkina, conducted various studies on approaches, that can be identified as social life cycle assessment. He found in his studies that S-LCA is related to the company behavior and consequently its evaluation is focused more on social conducts of the company and its main suppliers without taking account of the product life. However, a second method may be conducted along side the Environmental Life Cycle Awareness. This was carried out by UNEP/SETAC life cycle initiative. S-LCA follows the same steps as LCA but rather than using environmental impacts, the social ones are evaluated. This approach will be preferred in this work because our goal is to obtain complete sustainability assessment of frugal innovated products.

According to Social Assessment developed by, (M.Z. Hauschild et al., 2008) five groups of main stakeholders have been identified to be impacted by social impacts. The categories are workers, consumers, local communities, society, and value chain actors. The researcher and the data available must choose the stakeholder studied.

Social life assessment is difficult to discover, we understand stakeholders that can be impacted but the department of commerce has developed a manual of understanding social indicators. Social indicators can be examined in eight major areas; health, public safety, education, employment, income, housing, leisure, recreation, and population. Within each of these broad areas, concerns may be further identified and examined. For each social concern indicators can give statistical measures of important aspects of the concerns. Indictors will show the statues of the population of study; possibly showing what groups are being affected. These social indicators will show the status of a population but will also give ideas on what forces are influencing those statues. The indicators themselves are simply the first step toward a better understanding of how a society is impacted.

(Klpffer, 2003), researched social indicators and developed two main criteria for indicators: one that measures individual and family well-being, and one that measures end products. A case study describes that indicators of education were selected for an individual as achievement and attainment rather than inputs; which would be school budgets or number of teachers. Social indicators are restricted to the data available, so subjective information must be omitted in large part because it is rarely available on a consistent basis over time.

Jorgensen discovered in his paper methodologies for social life cycle assessment in greater detail. He compares different S-LCAs to determine to which addresses social impacts from an E-LCA like manner. He understands that social assessments vary by author and method but states there are direct and indirect social impacts on a given subject. He compares two tables of S-LCA that may be evaluated at end or midpoint. Therefore, he concludes that S-LCA is still in the developmental stage. The understanding of when, what, and where to evaluate social impacts is argued by many different experts.

(Klpffer, 2003), evaluated the social impact of marble products. He utilized the S-LCA that is parallel to Environmental LCA and researched stakeholders in the worker's category and discovered the social cost for working with marble. His indicators were salary, and believed the indirect effect of higher salary, increased the social impact positively. He compared two companies in cities that both worked with a marble quarry and discovered that individuals working for higher pay had better health. He believed salary was an indirect positive effect on social impact. This is debatable but the methodology he used was simple and useful to understand a small aspect of social impacts.

(Bowling, 1995) and (Peiró, 2006), researched in papers to determine what are social indicators able to predict social health. Bowling tried to discover what is important in the lives of people. He surveyed three thousand individuals and discovered health, finances, and relationships were of highest importance. He also discovered education and the environment are the least important to happiness for these individuals. Bowling believed health, the ability for individuals to do everyday activities without pain, was the most important aspect. He concluded

that people were happy because of their ability to work and provided for their families. Peiro measures the socio-economic conditions of happiness and satisfaction of individuals. He surveyed individuals in 15 countries and discovered that financial satisfaction does not have a strong relationship with happiness but rather other indictors such as age, health, relationship, and all range in different economic perspectives. Social indicators are difficult to understand true happiness. Hence, the basic necessities are the best indicators of social impacts and health.

4.3 Life Cycle Assessment: Environment

Fiksel, conducted several different studies of design for the environment that were relevant to the investigation in this dissertation, (Fiksel, n.d.). One noteworthy study involved the use of current design for the environmental practices and matrices. Fiskel investigated the need for designing for the environment in various aspects such as designing for disassembly. He understood that the product must be disassembled at minimum cost and effect on the environment. He used simple designs, that less complicates the process and minimized the use of adhesives that may introduce contaminates in landfills. Fiskel discusses the design process of energy conservation in production stage, product use, distribution of the product, and utilizing renewable forms of energy.

The designing of products with environmental limitations understood is important to all stages of their life cycle, including raw material extraction, processing, transport, component manufacturing, and many other stages. Fiskel's extent of detail is exhausting and unachievable by product developmental teams, but should at the minimum have designers be aware of the environmental issues.

Many texts underline the needs and concerns of the environment along with detailed steps in resolving problems during specific product life stages. Nikolaidis, Mourelatos, and Pandey used Environmental Life Cycle Assessment to understand the product's life cycle. It is used in countless papers and by researches around the world. Nevertheless, similar to the social life cycle assessment, there is no standardized guide. The use of ISSO 1440 will be utilized since it is a guide on product development with the consideration of the environment.

A case study conducted by Gonzalez, utilized Environmental Life Cycle Assessment on Mexican school desks, (González et al., 2003). The study researched wooden desks' impact on the environment. The LCA was used to evaluate potential impacts and suggest designs improvements. The study utilized information on the transportation of the wood, cutting trees, manufacturing, distribution, use, and end-use of the desks. The life cycle inventory, Phase 2, identifies outputs and inputs from the product, emissions, and waste in every stage. Data was then modeled into inventory data tables using economic allocation as a scale. The LCA accounted global warming gases, oil used, and wood wasted in the life cycle assessment, Phase 3. The interpretation showed terrestrial Eco Toxicity was the main concern with the product. All the while, abiotic depletion, global warming, ozone depletion, and eutrophication had minimum impacts. LCA conducted on environmental impacts seen here was very simple but may also be very complex depending on the evaluator's expectations and the product complexity.

4.4 Life Cycle Assessment: Economic

Bovea, (Bovea & Vidal, 2004), uses a simple approach on increasing a product value by intertwining environmental impacts and customer valuation. His research utilizes Life Cycle Assessment and surveys to understand the customer valuation. He understands that consumers with spending money would prefer environmental friendly products but they come with a premium. The study goes deeper by finding the indirect effects of environmental friendly products have a correlation with cost. The less materials used the better for the environment, and better for the customer approval. He develops an integration model that uses three different methodologies to determine how a product affects people's decisions and the environment. This paper is useful for it combined methodologies to understand and evaluate products. Bovea did not go into detail on a product but does allow for a general look at product development through the eyes of the consumer with environmental awareness.

A case study by Yamaguchi utilized Life Cycle Cost Standard to evaluate public transport heavy-duty buses, (Bowling, 1995). The study's goal was to compare product groups of natural gas and conventional gas power buses, each with the ability of accommodating 80 passengers. The boundaries were restricted to Germany and no vehicle older than two years of age. The inventory costs included investment, tax, fuel, maintenance, and disposal cost. The LCA discovered the investment cost of a natural gas bus was 11 percent higher, but fuel costs were dramatically lower than gasoline buses. The conclusion of the study discovered the natural bus had a lower life cycle cost compared to gasoline buses.

4.5 Frugal Innovation

The current texts on frugal innovation reviewed here, addresses the definition to a greater or lesser extent. Bhatti describes in his paper, "What is frugal?" a number of methods for understanding of frugal innovation through innovation in emerging markets, history of frugal innovation, constraints, and theory development. The author introduces how frugal innovation benefits emerging market and how it is deeply rooted in cultures and societies. He describes the differences in markets and how frugal innovation is an innovation that is meant to help the bottom and middle class populations. He then goes about discussing the past benefits of frugal innovations through example of wartime restraints in the UK. He shows that even a developed country may utilize frugal innovation in time of need. Lastly, he goes into detail how little work has been performed on the topic of frugal innovation and how a theory about the growth of innovation phenomenon is emerging.

In "The Emerging Market for Frugal Innovation," the author tries to identify the rhetoric surrounding frugal innovation and attempts to understand the discourse surrounding it as a fad, fashion, or fit, (Bhatti Yasser, n.d.). He also seeks to map the emergence of this market by suggesting drivers and making a social movement involving different actors pursuing both contentious and complementary approaches to achieve the same outcome; such as creating a value for underserved populations. A project of the Institute of Technology and Innovation Management sought out disruptive effects of frugal innovation when transferred to developed countries. Rajinish focuses on problems and solutions encountered by GE during recent Frugal R&D projects, (Tiwari & Cornelius, n.d.). He spent time looking at accelerated growth of emerging markets and their equally growing R&D opportunities. He conducts analysis of the

process governing success and failure of frugal innovations being transferred from developing countries to developed countries. The research consisted of gathering databases and analyzing the properties of frugal innovation transfer.

CHAPTER 5: METHODOLOGY

Frugal innovation is beneficial to people living in the bottom of the economic pyramid and to the environment. The origin of frugal innovation is unknown and a process to create frugal innovative products does not currently exist. This section will describe factors involved in the development of frugal innovation in India and will present a design model utilizing various methods of life cycle assessment to develop an efficient approach to frugal innovation.

5.1 Understanding Frugal Innovation

Frugal innovation originated and is in continuous use throughout India, (Future, 2012). The lingering question remains, why is India the birthplace of frugal innovation? The term was coined by the actions and products created in this nation. In order to explain why frugal innovation is centralized in India, various indicators formulate a comparison. This dissertation will go take a broad approach to reveal the characteristics between India and Brazil through analytical steps and selective markers such as education, economics, and external influences. As a root comparison to focus frugal innovation's success, information regarding both nations' characteristics was acquired from the World Bank Data Base, (WBDB) and various other individual studies. Markers were limited to income distribution, per capital income, economic growth, population growth, education, patents published, money spent on R&D, publications, quantity of researchers, growth domestic product (GDP), interest rates, and technological regulations. Relative similarities and differences within the data unveil possible explanations for why frugal innovation occurs. The process will be an observation between the two nations to conclude a hypothesis on understanding environments that promote frugal innovation. The

understanding of frugal innovation in various nations is imperative to developing a design process, "to know where you are going you must know where you came from", (Submitted, 2009). To help discover a frugal innovated design process for deployment in developed and developing nations, a basic understanding of India and its citizens is fundamental.

5.2 Development of a Design Process

This dissertation presents a design method for contextual assessment. The method is modeled after traditional design methodologies and integrates life cycle assessments, which a variety of outputs and techniques may be inserted. However, it extends beyond what any of the other methods offer by bridging frugal innovation design with sustainability. This method facilitates and directs the process of discovering, documenting, and applying information throughout the design process.

Current design processes, described in chapter two, provide insight into the utilization of the customer input as the primary source of validation and recommendations of ideas during the design process. The method of developing a product with a focused customer input is flawed. The reason being is in determining which of the many qualities that are suggested, can be included in the final product. A high influence in product design by customer suggestions creates a need for variations in models rather than single universal product. Increase production of multiple products increases the overall cost for all the products. Another obstacle in customer influence design is the information gathered by the customers is restricted to the observable effect the product has on their lives. Categories of insight can be observed by an increase in the

output a product generates for the intended customer. Ease of use of a product can be described by the customer in various forms and is dependent on the subjective perspectives of the users. The quality of usefulness in the product is a subjective characteristic making it difficult to measure. However, information regarding the effects the product has on the environment, society and economy are not easily obtained through the voice of the customer. The simplification of a customer's limited knowledge about a product's sustainable is understood to be inexpensive, environmentally friendly, and beneficial to the user. These are the three pillars of sustainability to the everyday customer. The details involved in understanding why the product affects each pillar are limited by a lack of information and alertness from the customer. There exists a need to apply sustainability into mainstream design processes.

Large corporations and government agencies understand the effects of a product throughout its life cycle by using life cycle assessments. There exist two flaws in the utilization of life cycle assessments. The first flaw is LCAs are retrospective: they are predominately used after a product has been completed and is already being used by society. This information is valuable to understand the effect the product has on sustainability, however, does not directly contribute to the design of a more sustainable future. Second, LCAs do not utilize a standardized format that can be used by all products for a baseline comparison across a product's effect, this prevents a universal goal of product sustainability . However, these two flaws of LCAs can be addressed for a new incorporation of LCA into the premise of frugal innovation design. LCA may be used during the creation of the product to incorporate sustainability to a product. The second flaw of not having a standardized format allows for structure to be created; a frugally innovated structure can be placed to give direction and goals to a previously unknown

evaluations. LCAs may be complex, long, detailed, and time-consuming assessments while giving little to no alternatives to a single product. However, with the use of several LCAs on different products with the same goal, sustainable alternatives will present themselves that can be utilized in alternative designs thus creating an optimal frugal product. The use of LCA in the design process can see and determine the effects of materials, processes, manufacturing techniques, and transportation of the product. Frugal innovative products are sustainable, have a low impact on the environment, and are beneficial to society and the economy by being profitable and growing local economies.

The following chapters combine the ideas of frugal innovation and LCA to create a design model that produces frugal innovations by its effects as well as being sustainable by design. The qualities of frugal innovation are directly and indirectly interconnected to LCA indicators that are proven measureable matrices. Frugal innovation does not exist as a structural design process nor is it taught in any academic venue. Nevertheless, through the observation of previous frugal innovation work and data collected, a design process can be developed. LCA is a complicated process that utilizes large amounts of information such as material, labor, and transportation that have an impact on all three pillars of sustainability (Pope, Annandale, & Morrison-Saunders, 2004). However, if performed with a design process that utilizes the voice of the customer, brainstorming, and frugal constraints, a product can be created that is truly sustainable.

The following chapters will present a complete understanding of frugal innovation. A national comparison between two nations will give some insight to understand why India is the birthplace of frugal innovation. This work is concluded with a case study of a treadle pump.

CHAPTER 6: WHY INDIA IS "HOME" OF FRUGAL INNOVATION

It is commonly stated and observed that India is the origin of frugal innovation, (Kirsten Bound and IThornton, n.d.). Recent research indicates that frugal innovation is a mindset of the Indian culture, a culture that has creative improvisation, (Future, 2012). India is a large market with an ever-growing population seeking to emerge out of poverty and enter into the middle class segments of their society. The growing economic base of consumers in India are extremely price sensitive, hence, are willing to purchase low cost products that will be beneficial to their lives. It is well documented that the infrastructure of India has major gaps in service delivery, health, education, and energy needs, (Tiwari & Cornelius, n.d.). India is also clearly understood and categorized as a developing nation with strengths and weaknesses similar to other developing nations. Therefore, the question remains why has India been the only nation to utilize frugal innovation or similar conceptual versions, placing itself into the global spotlight of its economic growth.

Frugal innovations have been discovered to be beneficial across several categories. For example, they are important for solving developmental challenges by providing solutions to aid developing economies. A slow growth in a nation's economy as well as its rapid high growth in population, will give rise for the requisition of frugally innovated products. In lieu of environmental concerns and constraints observed around the world, targeting trepidations concerning climate, energy, and pollution; ultimately compel the incorporations of frugal innovations to expand available solutions. The increasing size of an aging population within a

society will require new methods in providing health care in an efficient manner.

Numerous reasons arise on why there is a growing need for frugal innovations, notwithstanding only India or developing nations, but the entire world. The question remains why has India become the dominant nation in frugal innovations? This question helps set the stage in developing a design model in frugal innovation. To create anything, the question of why is vital to comprehend. The question is a broad one that cannot be answered with one answer but requires an understanding of a nation and its people. The following section will elucidate the reasons of frugal innovation by comparing India to Brazil in a numerous factors. The indicators are beliefs of my own that need to be understood and discovered. The indicators information is available through multiple international and national government agencies.

6.1 Frugal Innovation Country Comparative

The following section sets out to explain the characteristics of India and present a comparative analysis with Brazil. The comparison takes a purposefully broad approach, aiming to chart both Indian and Brazilian situations and direction. The goal is to gain insight and understanding on why frugal innovations dominate in India and not in Brazil. The reasons why one nation provides frugal innovation while the other does not, gives valuable information in order to create a design process that can adapt to many other settings. The information will provide valuable understanding into who, what, and why frugal innovations are conceptualized in India.

6.2 Background

6.2.1 INDIA

India is located in South Asia bounded by the Indian Ocean. It is one of the oldest countries in the world and subsequently encompassing one of the oldest preexisting cultures dating 5,000 years ago, (Tiwari & Cornelius, n.d.). India has 28 states, each with their own dialect and unique constitutions, 7 union territories, and is the seventh largest country by area yet has the second largest population with approximately 1.2 billion people, (WBDB, 2013). Relatively new, India became an independent nation in 1947 previously ruled by the United Kingdom since 1858 only to become one of the world's largest democracies, (Ghosh, 2010). India's geography consists of the Himalayan mountain range, Thar Desert, and Ample Forested Mountainous regions where recently unknown species are being discovered, (Akkiraju & Roy, 2011). Natural resources utilized in India range from mining of multiple minerals such as iron ore and the production of petroleum, (Madon & Sahay, 1997).

6.2.2 BRAZIL

Brazil is located in South America, bounded by the Atlantic Ocean. Existing as the fifth largest country, both in area and population, occupied by 193 million people, (WBDB, 2013). Brazil has 26 states located in four major Brazilian regions. Brazil became an independent nation in 1822 from Portugal's 300-year-old reign, (*Brail Vs India, n.d.*). Brazil is the home of Amazon rain forest, which shares half of the planets remaining rain forest, Corcovado Mountains, and the Amazon River, which runs through Brazil. Natural resources found in Brazil vary from petroleum extraction to mineral extraction, (Madon & Sahay, 1997).

6.3 Comparisons

I will describe the similarities and differences between two developing nations, India and Brazil, through economic, social, and educational markers. Brazil and India are comparable in many characteristics, however, have a few distinct differences that helped push India as the founder of frugal innovation.

6.3.1 INEQUALITY

Economic inequality is the difference in the distribution of economic assets and the income between the populations. The first indictor used is the GINI index, a measure of statistical dispersion of an entire nation. The GINI index is used to measure inequality in income and wealth within a nation, (Ogwang, 2007). The GINI index uses a scale of 0 to 100, where zero is perfect equality and 100 is maximal inequality, (Ogwang, 2007). The index representing India is 34 and 55 in Brazil, (Ogwang, 2007). These two numbers demonstrate that the money is allocated in various individuals through out the nation. Not one person has all the money nor does everyone share everything, but both numbers demonstrate there are economic gaps between the populations. The notion that people have and some do not is not new but does show that individuals do require products that range in cost since affordability varies across both nations. The inequality is observed between the five regions in Brazil and between the three regions of India. Per capital income and economic growth in Southeast Brazil is seven times greater then the Northeast region, (ANNEXURE 2007). India's inequality per capital income gaps is three times the amount from one another, (Briefing, 2013). The cause of inequality is the wealth concentrations, labor markets, educational costs, and racial inequality, (Briefing, 2013).

Inequality has been found to affect health and social problems along with lower rates of social goods and low economic growth, (*Brail Vs India, n.d.*). The income distribution matrix is determined by the production, land, labor, and capital of a nation or region, (Bakker & Creedy, 2000).

6.3.2 DEMOGRAPHICS

To understand the people and how they live is extremely important. Demographics of a nation are clear quantifiable statistics for a given population. A population that is innovating is doing so for a reason, the reason found is to provide for their needs. With populations in the top largest in the world, Brazil and India have a diverse culture. A large amount of people governed by one nation comes with large needs. India has a population of 1.2 billion people while Brazil has a population size of 196.6 million people, (WBDB, 2013) The difference between both nations is dramatic but compared to the world; Brazil and India are both in the top five largest population category in the world, (WBDB, 2013). Brazil's total percent of world population is 2.8 percent while India is 17.8 percent, (WBDB, 2013). Population demographics depict a large number of individuals living in both nations however other indicators are needed to understand the people. Infant mortality and life expectancy help show the health situations with the population. India is recorded to have an infant mortality rating of 44 deaths for every 1000 births and while Brazil has 25 deaths for every 1000 births, (WBDB, 2013). These numbers are significantly higher then the US with 4 deaths for every 1000 births, (WBDB, 2013). The life expectancy of India and Brazil average 70 years of age while in the United States the life expectancy averages around 80, (WBDB,2013). The health situation in both nations is in need of

assistance, this can be observed from the high infant mortality rates and low life expectancy statistics.

The next factor observed is the population growth, a change in population over time. Population growth exhibits the individuals in the nation are propagating or individuals are moving to the area. India has a population growth rate at 1.41% while Brazil has less then .9%, (WBDB, 2013). The numbers indicate both populations are growing but more information is needed to be gathered to understand if its from families growing or immigration. Never the less, nations are positively growing however, India has a larger rate of growth, does this indicate a stronger nation?

The last indicator that must be understood is the population density level of urbanization. This indicator demonstrates where the population is centralized at; Brazil has 87% urbanization population while India has 30%, (WBDB, 2013). The illustrates many people are living in rural areas in India, making a large population out of reach of urban assistance such as water and electricity, (Ghosh, 2010). This is important to understand what needs are being and not being provided by each nation. It is difficult to provide water, electricity, waste systems, and health care to a largely spread out nation.

The demographics of a nation are important information to understand for frugal innovation. Frugal innovations must appeal to large number of people in order to create profits. Both nations are proven to fall short in providing these needs to millions of their citizens. This lack of assistance from a government opens up an opportunity for inexpensive products that

provide for the needs to flourish. Frugal innovations provide a need in health care as well, which both nations have inadequate systems in place. However, the question still remains why India is the home of frugal innovation and not Brazil. Demographics are an important part but is not the only indicator needed to instill frugal innovations. The next section will dive into education backgrounds of the populations and the education opportunities provided by each nation.

6.3.3 EDUCATION

Kirsten Bound and Lan Thorton interviewed 130 Indian policy makers, entrepreneurs, and academics to explore policies of the educational system of India as compared to those of other nations, (Mehrotra, 2006). The research compared India's development, strengths, and geography in research and education. The government of India proclaimed innovation as a national agenda, although R&D expenditures are less than one percent of total GDP, (Mehrotra, 2006). The mindset of the India government is to encourage innovation but data demonstrates not much is being done or produced out of India, the same low production numbers can be observed in Brazil. The money spent on research and development in India and Brazil are both averaged at twenty billion American dollars, (Gupta, Verhoeven, & Tiongson, 2002). This number looks high however it is less then one percent of the total gross domestic product. The United States spends 405 billion and South Korea allocates more then 4% of its GDP to research and development, (Gupta et al., 2002). The need to provide money to research and development is a status quo in creating inventions and innovations for a nation. Even with low funding in India, frugal innovations are still being developed and thriving. So the amount of money of R&D is not the source of frugal innovations. The money spent on R&D has a direct correlation with the number of researches. The number of

researches in R&D for both nations average fewer than 200 thousand individuals; the number is dramatically low for the top 5 largest populations in the world, (*A macro-economic view on the past, present and future of brail vs india*, n.d.). As an outcome for the low number of researchers and funding the publications and patents produced by the two nations demonstrate significant lag behind many nations, (Tiwari & Cornelius, n.d.).

The education systems in both nations are inadequate due to low government funding. Indian and Brazilian governments state "education is a fundamental right", (Ramachandra, 1996). However, the funding provided is for children between the ages of 6 to 12, (Mehrotra, 2006). The limited education opportunity provides the average citizen in Brazil to obtain 4.9 years and 5.1 in India years of education, (WBDB, 2013). The limited amount of education can be observed through the low literacy rates reported in both nation 74% in India and at 85% Brazil, (WBDB, 2013). The literacy rate demonstrates individuals that can understand, read, and write a simple statement for everyday life. The literacy rates do not demonstrate the ability to comprehend complex books or instructions. This is important to understand for frugal innovation, since frugal innovations must be easy to operate with out complex instructional manuals.

The higher educational statistics is important to understand for frugal innovations as well. It has been observed that many ideas, breakthroughs and inspiration have come from higher education establishments. The numbers of universities ranked in the top five hundred in the world are scarce in India and Brazil accounting for a combined seven universities, (*A macro-economic view on the past, present and future of brail vs india*, n.d.). The limited amount of

universities in the nations suggest intelligent students to study else where, such as the United States. Currently 105,000 students in American colleges came from India, this number is growing with a 20% increase in student visas, (Song, Gartner, & Tasci, 2012). This demonstrates that the two nations have a lag in education availability and productivity. The low number of institutes and students demonstrate that high number of frugal innovations do not come out of the academia setting many may believe. Frugal innovations are for the bottom of the economic pyramid and are created by this group as well. To attend a university in a developing nation proves to be for the wealth class, (Brook, 1988). Regardless of the absence of strong research institutions, India is still considered the predominate nation for frugal innovations. The account of frugal innovations cannot be understood under the normal academia or research manner. Where are these innovations coming from? The next section will look into the economic aspects of both nations to determine how money influences frugal innovation if at all.

6.3.4 ECONOMIC

Economics is an important but variable aspect to describe for an individualistic nation. Economics can encompass a nation as a whole or its individuals, with many indicators such as income, taxes, consumer price index, inflation, and unemployment. The following section will take a look at a few indictors to get a broad understanding what is occurring in the two nations. The first indictor I researched was the gross domestic product (GDP). Brazils GDP per capita was observed to be $5,900 compared to India $2,800, (WBDB, 2013). The per capita GDP is especially useful when comparing one country to another because it shows the relative performance of the nations population. The GDP of Brazil is higher than that of India, however,

both in retrospect to the global market are considered low developing nations. The individuals in both nations make considerable less income compared to the world market preventing them from purchasing products at the world market rate. The need for products that are competitive but affordable is imperative to both nations and other developing nations. Two other economic indicators I came across are unemployment rate and consumer price index, inflation, (Del Negro & Eusepi, 2011). The unemployment rate in India is 3.8 and Brazil is 4.7, (*A macro-economic view on the past, present and future of brail vs india*, n.d.). These numbers are respected and good for the nations for it shows that individuals do have jobs in the nation, however, the earnings are extremely low. The inflation of Brazil is at 6.5% and India at 11.4% inflation, increase in prices and fall in purchasing value of money, (Del Negro & Eusepi, 2011). India inflation is considerably higher then Brazil making the reliance on trade of products and do it your self products important. Since the cost of the products are high and the money they have to make the transactions is less valuable. The next aspect about the economy is the taxes placed by the governments on individuals and foreign investors.

A very important indicator that all nations have in common is taxes. The taxes of a nation help the government's ability to assist their people in various ways, (Das-gupta, 1996). The debate exists on what is a proper amount to tax ones people and foreign nations that do business in the country. The tax debate in the United States is highly passionate, however, taxes are essential to all economies. Although, the two nations we are comparing are developing nations they both have taxes. The taxes enforced in India and Brazil is different. Brazil's tax infrastructure is at 40% of the GDP, a high tax rate, (Baer & Galvão, 2008). However, in India, the tax system is similar to international standards, which shows a significant difference between

the two nations, (Das-gupta, 1996). The lower taxes provide incentives for foreign and domestic companies to establish themselves in India. Along with lower taxation a marker of ease of finance is the interest rates and accessibility to loans, which vary in both nations. India's government shows favorable actions towards individuals and companies to borrow money to establish businesses, (Brazil Vs. India, n.d.). However, in Brazil, over 50% of companies that need loans decided not to apply, due to complicated applications and high interest rates, preventing them, (*Brazil Vs India, n.d.*). The interest rates for borrowed money in India is dramatically lower, at less then 7 percent while in Brazil is higher the then 13 percent (Brazil Vs India, n.d.). The amounts is dramatically large for a small business to establish itself. The costs and low profits made by a business can be detrimental if the business obtained loan that have high rates. The higher taxation and high interest rates in Brazil do not make it an optimal place to start a business or bring one in from another nation. The Indian mentality of taxing at a standard rate and providing low interest rates to the business is a way to stimulate business growth by the people and promote business coming in from developed nations. The lure of this brings in foreign nations to establish business in India this can be seen by the service sector of India. The next section demonstrates foreign influence and interests in India.

The last aspect I researched was in the employment of the citizens in both nations. The majority of the populations in both nations work in the service sectors, (Baer & Galvão, 2008), (Das-gupta, 1996). Service sector composes of labor, manufacturing, and various jobs individuals do. The service sectors in India are construction, trade, hotels, transport, restaurant, communication and storage, insurance, banking, business services, and real estate, (*Brail Vs India, n.d.*). The service sector contributes to the 50 percent of the total GDP and provides a

quarter of the employment, (*Brail Vs India, n.d.*). The reason for such a large number in the service sector is the interest foreign nations have in India. Foreign nations outsource work to India because of the large number of highly skilled and unskilled workers, and low cost of labor, and resources. A cause of outsourcing from foreign nations, India has had large growth in business processing and the technology industry, (WBDB, 2013). The highly developed technology and information influence brought in from foreign nations provide India with opportunities to utilize new knowledge in combination with low-income societies to create frugal innovations. In Brazil, the service sector accounts for 65% of the gross domestic product and contributes to 43% of the employment, (WBDB, 2013). However, the service sector in Brazil is limited to land, air, and water transportation.

Information and technology are extremely regulated and controlled by the Brazilian government. The lack of technological trade prevents an exposure of new information and technology to flow in and out of the nation, inhibiting the growth of frugal innovation. Brazil for decades and to this date has had strict trade barriers preventing the export and import of foreign information and influence, (Baer & Galvão, 2008). Industrial, Technological and Foreign Trade Policy (PITCE) the innovation act, biosecurity act and the biotechnology development policy are all new policies that are trying to overcome the past policies of restrictions in Brazil, (Baer & Galvão, 2008). The high trade tariffs also prevent trade to flourish in Brazil,(Pii, 1997). However, India utilizes WTO policies, which are very open for expanding and introducing foreign influence in and out of the nation, (Pii, 1997).

The comparison of Brazil and India showed similarities and differences. No clear understanding can be gained from the simple view of the research provided in this dissertation. However, a hypothesis on why India is the birthplace of frugal innovation can be stated. There exists a high demand for products that support the needs of a highly populated poor community. The sources of frugal innovation are not created by educational settings, but rather inspirations from foreign influence of technology and the opportunities a nation provides its people to create an idea into a business. The need of frugal innovations are obviously seen by a billion people not having the basic necessities because the cost of obtaining these products are out of reach. The comparisons of Brazil and India demonstrate that new ideas and information from developed nations can inspire innovation of the same product but in a new bottom of the pyramid design.

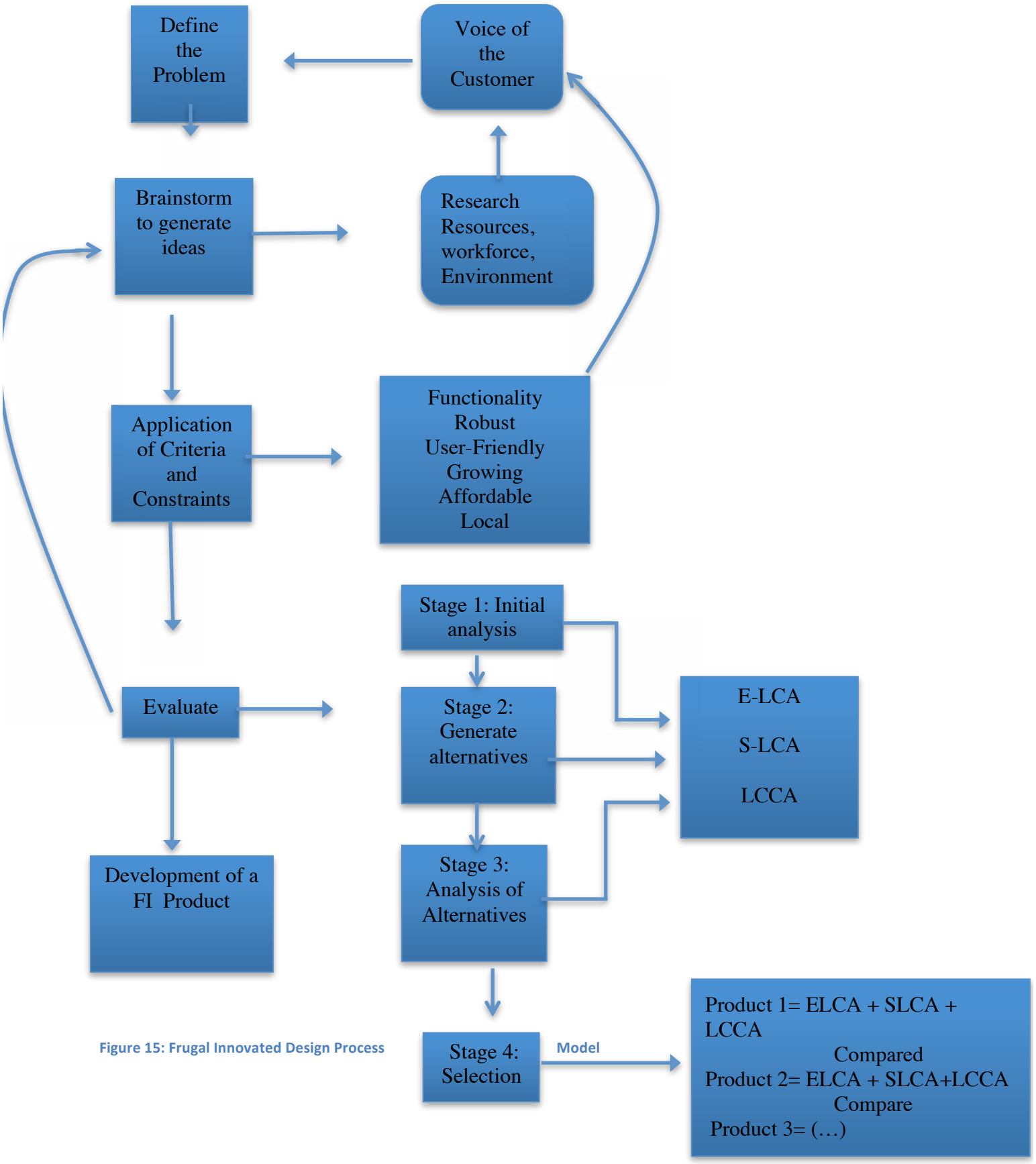

Figure 15: Frugal Innovated Design Process

CHAPTER 7: DESIGN PROCESS

7.1 The Design model of Frugal Innovation:

The research presented throughout this dissertation supports the idea that frugal innovations have the potential to achieve sustainability. However, there is no systematic process to develop frugally innovated products. The following is a model to help make decisions in creating frugal innovations. Models are a scientific approach for simplifying complex systems. Models are known to be successful if users have clear explanations to guide them throughout the process. Making a model of a design process helps ensure all stages are completed. In addition, it helps ensure that the problem will be answered in a short amount of time. A process shows a complete documentation from start to end in a systematic order for ease of replication. Lastly, it helps engineers and other participants to focus on the current stage, and produce the best product.

Current design processes focus on several aspects of design, the first of which is to gain an understanding of the customer's needs, wants and required specifications of a particular product. Previous chapters discuss design processes and methodologies focusing on these various areas of design. Fuzzy front end of a conventional environment design provides insight on understanding the needs of the customer along with a consideration of the environment. This process is vague and considered virtually impossible to include all qualities into a single design model. However, the notion of including customer inputs, as qualities into a product is essential for the successful acceptance of the product by the customer. However, sustainability cannot be

based solely on the information and criteria given by the customers but must be built into the product. Currently, designers and marketing departments use a system for producing products, similar to the Design Process method (González et al., 2003). Design Process method is an over view of a products realization to conception and everything in-between. Conventional Design Process focus on creating a product that is low cost and successful in completing it intended objective. The steps in development begin with the marketing department, whose intent is to produce a specification for a product by obtaining data from intensive research of customer needs and wants. Next, the designer generates preliminary ideas, which ultimately take form of a working prototype. The marketing department tests the prototype, recommends alterations and approves the product for sale to the public (Hara, 2007). The design process is a linear sequence of events that has a start and an end point. However, this method of designing is time intensive and does not facilitate the implementation of sustainability into the product.

The uses of Life Cycle Assessments (LCA) are utilized in the context of a finished product's effect on sustainability. Life Cycle Assessments tools range from environmental, social, and cost evaluations. When used jointly, this creates a sustainable life cycle assessment. The complete incorporation of a sustainable life cycle assessment is not as common compared to environmental life cycle assessment, due to the enormous amount of data available and the number of factors to take into consideration. With the simplification of LCAs and use of specific indicators one can determine an optimal product that will help simplify the process. LCAs can be used to see unforeseen effects on the three pillars and to present an immediate red flag on detrimental aspects allowing changes to be made before harm is done. This immediate

understanding of a flaw shortens the time of discovery by conventional design, which discovers any flaws while being used by customers. LCAs have many indicators to determine all aspects of a products effect; this creates a time intensive and complex assessment. The individuals that use the LCAs determine which indicators to focus upon.

The theory of Frugal Innovation is not commonly found nor utilized in industrial or academia settings. However, it provides products to billions in order to sustain their life's needs. The understanding beyond what frugal innovations are and the effects were insufficient in creating a design model. A broader understanding of where and who practices frugal innovation and what influences help accelerate frugal innovation into society was needed. A comparison of Brazil and India was essential to the dissertation in order to uncover the basic premise of why frugal innovations exist in one area and not in others. The information will provide insight on recreating frugal innovations in new settings and societies. The outcome from the information available and the comparison demonstrated core qualities of frugal innovations. Frugal innovations are created by the combination of a society with limitations in providing basic necessities to its people, an influence of modern technology to a developing nation, and the opportunities in business created by a government to promoting entrepreneurs. These qualities all combined in one nation to create frugal innovations. The contextual factors involved in frugal innovations are being functional, robust, affordable, user-friendly, directed towards a growing economy, and utilize locality to its maximal. Along with the qualities of frugal innovations the goals and intent can be summarized as utilizing the voice of the customer, focusing on the needs of many, reducing excess waste throughout the life of the product, discovering new methods in

all areas of life cycle, reduce profits to a minimal, and utilizing the process of iteration. This is similar to the process of trial and error, with the effect of learning from the previous steps. The combination of all qualities and explanations of frugal innovation has not been organized into a simple design procedure to streamline the process.

This leads to the rational that a modified design process must be created in order to give change to a broken system to innovate. Frugal innovation utilizes inspiration, exposure, and a need to create solutions. The process is difficult to teach or even accomplish. However, a set of explanations and guidelines can provide frugal innovation order and recommendations on accomplishing a successful sustainable product. Figure 15 is my development of a design process model for frugal innovation. The process provides a simplified model of frugal innovation with boundaries, constraints, and areas upon which to focus in order to obtain a grasp on the design process of frugal innovation.

Full details in designing products are not meaningful for inspiring frugal innovation, however a model that idealizes the matrix is much more beneficial. This involves the simplification of the detailed guide to produce a basic model through steps and procedures that can be modified. This unfixed template encourages idealized aspects that depend on the application and details of the product. The frugal innovated Design Model in Figure 15 is a simple model describing a process and tools to formulate a frugally innovated product. The process is broken down into five main sections with sub sections that are essential to the development of a frugally innovative product. The five steps consist of:

- Define the Problem
- Brainstorm and Generate Ideas
- Application of Criteria and Constraints
- Evaluation
- Development of a Frugal Innovated product

The entire process of designing frugally is similar to the conventional design process. However, consists of different approaches in gathering data, the amount of influence the customer has, and the evaluation of various design ideas. The following descriptions give an empirical understanding of the process of frugal innovation and the usage of context upon customer product preferences. The customer preferences are strongly influenced by intended usage of the product, expressing attributes valuable to designers. The individuals using the product are the main source of information to understand the needs and the problem presented to them. The first step in frugal innovation design is to define the problem. To design a successful product one must have an adequate understanding of the needs of the customer. To obtain this vital information, it may be more difficult for one product over another. The beginning of the design process understands the contextual needs assessment; a systematic process for determining and addressing needs or gaps between current conditions and desires.

7.1 Define the Problem

Defining the problem is an essential first step to frugally innovate. A problem is an

obstacle affecting an individual or community in a negative manner. The basic needs of life include but are not limited to water, food, shelter, and security described in previous chapters. To define a problem, a designer must understand the challenges, goals and opportunities involved with the targeted customers. To begin this process, the designer must understand the customer by asking generalized contextual questions to obtain a starting point. The purpose of these questions is to narrow down problems to discover information needed to begin designing.

The causes of the problems can range from people, resources, environment, or process limitations. The frugal innovated design process is directed to solve problems dealing with needs such as health, water, food, shelter, or safety. The source of finding the problem derives directly from the individuals that live with the problem and not based on assumptions from designers from impersonal data sources. The gathering of information about contextual factors involved with product design is best done with general questions. The way to gather answers can be done with various techniques known as the voice of the customer (VOC). The Voice of the Customer is a tool that ensures the problem is defined correctly. VOC is a set of tools used to understand the needs and expectations of the product being developed, (Bralla, 1986). VOC exploits proactive methods of capturing data from the targeted group; VOC methods include interviews, surveys, and focus groups. Each method can be used independently or collectively to get the best understanding of the needs.

Interviewing is a data collecting technique used to provide specific customer point of views through several methods of contact such as person-to-person, phone, or mail, (Fiksel, 1996). The strength of this technique is that the designers get a one on one understanding from

the customer. However, the sample size is small and the cost of obtaining more interviewees becomes time and money intensive.

A survey is another VOC data collection technique that measures the needs of an entire population, (Leech & Turner, 1985). Surveying reaches out to a larger group and many customers, however, the response rates to the survey are commonly low.

Then there are focus groups, which utilize eight to twelve individuals from an targeted area to gather information on perceptions, beliefs, and opinions about the needs, (Ulrich & Eppinger, 2000). The flaw in this type of technique is that the group influences each other thus creating a similar perspective with little variation.

The use of the VOC of the customer is an important portion to frugal innovation. The individuals that live and work in the environment that will operate the product have an insightful understanding on what is needed. However, the quantifiable factors in the design must be discovered by the developers to foster a successful product. This is the reason why questions must be general and open ended since the customers do not know exactly what product they want but do know what problem they need solved.

The information obtained from the customers can be gathered either by direct or indirect processes. Context of the questions must understand how the product will be applied, where the product will be utilized, and who will operate the product. These three context factors can help designers understand various obstacles the product must overcome. The task on how the product

will be applied can help one to understand the application and function of the intended product. How will the product be used? What will the product be used for? The "how" contextual factor question tries to understand the frequency of the usage of the product by asking, "How often will the product be used?" Discovering time duration a product will be used by asking, "how long will the product be used for each time of usage?" The context factor dealing with where the product will be used focuses on the surroundings, weather, energy costs, and availability of energy to the intended areas. Questions to be asked range from: "What types of surroundings will the products operate in?" "What are weather/climate conditions the product will be exposed to?" "What is the cost and availability of various energy sources?" The last contextual factors to understand will be about the customers and their characteristics. This will give an understanding and guide to the users themselves, the skills and education of the customers and physical understanding of the users abilities such as strengths, control, and range-of-motions. Questions that may be asked may be: "Who will use the product?" "How familiar is the user with the product?" "What is the user's education level and age?" "Does the user have any physical condition that may interfere with using the product?"

7.2 Brainstorming and Generation of Ideas

The second step in the design process is to develop solutions. The concept of frugal innovation is not to invent but to innovate. In its purest sense, "invention" can be defined as the creation of a product or introduction of a process for the first time. "Innovation," on the other hand, occurs if someone improves upon or makes a significant contribution to an existing product, process or service, (Benner, Linnemann, Jongen, & Folstar, 2003).

Brainstorming is the generation of ideas and utilizes the information gathered in the previous steps along with new information about the environment of the targeted market. Valuable information and questions needed for the frugal innovation design process are:

- Determine available resources
- Determine skill level of the work force
- Understand the environment in which the product will be utilized
- Determine economic strength and willing price
- Discover similar products in the market

The Generation of Ideas is the step that sheds light on what can be done. Generation of Ideas has no limitations. Everything possible is taken under consideration, regardless of how extreme or obvious. Ideas in frugal innovation can be off topic as possible since a core quality of frugal innovation is utilizing new methods throughout the life of the product. New methods cannot be viewed as obvious unless individuals with various perspectives are involved in the brainstorming portion of the design process. Ideas may be unconventional. Nevertheless, the more creative the ideas are the better chances of discovering a novel solution. Generation of Ideas during the brainstorming portion is best performed with the combination of individual and group brainstorming sessions. Individual brainstorming for frugal innovation requires the individual to observe and participate in the environment where the problem exists. This gives hands on opportunity to clearly gather ideas. The group brainstorming is the combination of the designers, engineers, scientists, and any non-conventional designing individuals available. The individuals who will use the product must be actively involved as well. The insight, behind inviting non-conventional designing individuals, encompasses a variety of different perspectives

within a team, may arise in finding more radical and newer ideas. Details on location, questions to be asked are dependent on the problem defined.

When a team is gathered to brainstorm ideas, finding solutions for the defined problems, research of the target group must be readily available. Research must be provided to the brainstorming group that is quantified information. The data must include but not limited to workforce levels, education, availably of resources, environmental conditions throughout the year and extreme conditions that are plausible to occur during the operation of the product. Research must also include information about the target group on educational levels, income, language, physical stature and other relevant information available. The last would be research on similar products available or methods that can be utilized. One must understand what other products are available to solve the problem but understand why they have not been accepted.

Familiarity is an indicator that determines the amount of outside experiences the brainstorming team has on the product. The second indicator, *accessibility*, is a measure of increasing the familiarity of the team to the product through observations and communication. The last indicator is *uniformity*, which is a measure on how much variation can be done throughout the design process. The design team must utilize the three indicators to understand the application of the product, environment the product will be operated in, and the customers operation of the product. The limitations created by conventional design can be bypassed with the VOC.

7.3 Identify Criteria and Specify Constraints

Step three, narrows down ideas discovered in the previous step by applying design criteria and constraints. Currently there exist two sources on what qualifies as a frugally innovated product from Santa Clara University and Roland Berger study of frugal innovation. According to Santa Clara University guidelines, for a product to be a frugal innovation design, the product must meet the following characteristics:

- Lightweight
- Rugged
- Affordable
- Simple
- Green
- Use of local materials and labor
- User centric
- Adaptive

Roland Berger creates a list of frugal innovation characteristics by surveying sixty individuals in the area of frugal innovation to determine the importance of each aspect in the process of design. The results of the surveys suggest that all qualities are important and need to be addressed in any design process of frugal innovation.

Berger's lists of six aspects of frugal innovation are:

- Functionality
- Robust

- User-Friendly
- Growing
- Affordable
- Local

The two lists of qualities are similar, forgo, vague in the description. The frugal innovated design criteria and constraints are to be determined by the area and problem of focus. However, the product must be designed to fit the need explicitly, be tolerant of the environment of the intended market, use local workforce, materials to its maximal ability, and be easy to use by a society that has low literacy rates. These are the practical constraints to the frugal innovated design process, but the intensities and variation of degree are dependent on the problem and location.

7.4 Evaluate the Design Using LCA

The evaluation of the design is critical for frugal innovation. Frugal innovation currently relies enormously on the process of trial and error. The trial and error process has an extremely high turn over rate compared to several of other R&D techniques. Trial and error is the process in which the person tries many different ways in order to come to a solution that is acceptable. However, trial and error is a time consuming, expensive, and non-efficient way to determine the optimal product. To institutionalize frugal innovation as a design process, trial and error will be replaced with LCA assessments and iteration. Using LCA in an iterative manner allows developers to learn from mistakes and build off of them.

LCAs have a range of operational techniques ranging from evaluating a product that currently exists to evaluating the materials the product is made from. LCAs determine the environmental, social, and economic impacts throughout the entire life of the product. Life of a product is considered the acquisition of raw materials, transportation, manufacturing, operation and disposal. The extent of a LCA is completely depended on the individual that creates the LCA. This gives opportunity to create a LCA that utilizes sustainable frugal innovation as a guideline. Frugal innovations criteria are vague and non-specific. However, LCA are quantified and specific thus allowing for observation of effects in various aspects of a product life cycle. The numerous amounts of indicators give rise for creative thinking on application of indicators to focus on the concept of frugal innovations.

Frugal innovations are currently not understood in any extent by being evaluated through LCAs in order to determine what is beneficial to sustainability. A hypothesis backed with literature and research gives rise to a correlation between LCA indicators and frugal qualities. The list below provides suggested indictors to be assessed in the LCA evaluation of the product. The LCA will not only provide areas being effected by the product but can help evolve the process of design. LCA of various ideas and products can demonstrate strengths in one product and weakness in others allowing for substitutions to be made creating an optimal sustainable frugally innovated product. The use of iteration and LCA gives the notion of improving the design process each time a LCA is processed. LCAs will be used multiple times on the same product design after an alternation has been done. The iteration of LCA will substitute the need

of creating a product and determining the effects and modification on a prototype.

Life Cycle Assessments primarily are known for environmental evaluations, however the environment is only one of three pillars of sustainability. LCAs for social and economics are less known and understood but do exist and will be utilized. Social LCAs focus on the individuals that interact with the product. The stakeholders and the evaluations were discussed in previous chapters. The economic LCA also known as Life Cycle Cost Assessment (LCCA) is an evaluation of the total cost involved in the process of developing a product. Other factors included in LCA are the effect on the gross domestic product of a nation and income provided to a community.

The indicators proposed to be utilized in frugal innovation design process for environmental indicators are material and energy intensity, material recyclability, and product durability. Material and Energy Intensity was chosen as an indicator of frugal innovations in lieu of a variety of reasons. Frugal innovations have the qualities of being sparing of resources classified as energy and materials. The indicator depicting a *reduction in materials and energy* intensities gives insight to specific areas of manufacturing and use that show waste. This allows evaluators to examine areas and provide improvements to replace materials or a process to the sparing of waste and generation of a simplistic product. Material intensities are evaluated by weight. These are standard measurements that can be used to provide relevance for comparison from one product to another. The second environmental indicator is *material recyclability*; this indictor represents the usage of renewable materials. This is not limited to physical materials but

includes renewable energy as well. This indictor is evaluated by the ability to reuse a material and the renewability of the materials such as renewable energy sources. Frugal innovations are considered the utilization of green energy, however this is not defined clearly. The use of green in frugal innovation can vary from the production of the product or the operation by renewable energy. The cost of renewable energy in a product creates increase cost in the overall product limiting the amount of an individual's ability to purchase the product. Hence, material recyclability is a measurement on the source of materials and energy in creating and operating the product. The measuring matrix for material recyclability is the ability of the material and energy to renew itself either by recycling or by creation. The amount of energy made from renewable material and the amount of the product in weight used. The last environmental indicator is product durability indicator. The *durability* indictor demonstrates the resistance of failure the product has in its environmental conditions and usage. The concept that a product has high durability and longevity reduces the need for customers to purchase the same product again. This matrix reduces the amount of energy, material, and time needed in creating multiple products. Durability matrices are determined by longevity and deterioration. These can be represented either by warranty the product has by its manufacture or studies in evaluating the time the product is no longer useful.

Economic indicators utilized for the evaluation of frugal innovations are Value Added, Contributions to GDP, and Income Distribution. These indicators will provide insight into the economic effects of the product in an intended target market. *Value added* is the effect the product has on a person's life. Since the product is inexpensive, this allows for an increase customers life by allocating monetary resources in other vital areas. The value added matrices

reduces the cost of the product throughout the life cycle and insures the product has the highest possible value for the cost. The intent for this indicator will represent a frugally innovated product that is competitive with high cost alternatives. As well with satisfying the need but reducing the overall cost of the product. The value added can be measured by monetary quantification throughout the LCA, in the materials cost, energy cost, manufacturing cost and transportation cost. The Second indicator used is *contribution to GDP*, this will provide improvement of the economy of the society being targeted. The contribution to GDP is a representation of the services and products allocated within a nation. The measuring matrix for Contribution to GDP can be seen through many national measurements. The immediate effects of a product on a nation's economy may not be dramatic; however, the intended overall goal of these products is to assist the developing nation strive for development. The manner to create a product that contributes to GDP will be through the localization of the product development. This is the centralization of manufactures, vendors and materials from the targeted area. The use of local labor and materials will increase the GDP of the nation and keep the product cost low by reducing the high transportation cost associated with international trade. The third indicator is *income distribution*; this indicator helps allocate the income created by the selling of the product and use of the products. The income distribution matrix realizes the need required in the design process of local distributors and manufactures. The need to create a product that can be manufactured and assemble in the developing nation is essential. This will create income distribution throughout the nation and within the community. The measurement of income distribution is inequity of wealth related directly from the product's life cycle. The Economic LCA is a tool that can observe the effects a product has on an economy, local, national or worldly. The concentration of LCA is to focus majority of the money in the location of the

targeted area. This will assist in the nation's developmental growth, rather than having outside nations reap the rewards by selling foreign products.

The last LCA is focused on Social impacts. The indicators utilized are Human health, Preservation of Culture Values, Satisfaction of Social Need, and Fair Prices. These indicators describe the basic focus of frugally innovated products, to help the customer, their community and their nation. Preservation of culture values is essential in the understanding of a products usage and place in the culture. This is essential to recognize how the product will affect the culture, either if it can merge smoothly into the current life style without creating much turbulence or if the product affects the culture negatively. If these are not fully studied, a product that is innovated and useful will not succeed if the culture is not accepting of the product or disturbs the norm. The *satisfaction of social needs* is an indicator to determine if the product does help the basic needs of the society, as discussed in previous chapters. The focus of frugal innovations is to help the customer have a better life. This can be understood by evolution of the product's entire life cycle. The manufacturing, acquisition of raw materials and distribution of the product cannot be harmful to the society in any manner. The next indictor is *fair prices*. This indicator is spread into the economic and social pillar by understanding that the products must be affordable. Affordability is determined by the income and ability of a customer to purchase the product. The fair prices must be compliant with the constraint of the customers. This will account for the reduction on profits. However, with a large volume of individuals purchasing the product will create large sums of profit for all levels of product life. The last indicator is *human health*, which is an easier matrix to quantify for it incorporates life expectancy, morbidity, and nuisance. The human health of the individual utilizing the product

must not be affected either by the manufacturing of the product or the operation. This includes release of toxins into the environment or the use of toxic materials within the product. The social indictors represented are important for frugal innovation. Therefore, many are difficult to measure and quantify throughout the design life cycle assessment. The effects can be modeled to determine if the stakeholders involved will endure dramatic social hardships.

The use of the three Life cycle assessments is essential in creating a frugally innovated product. Hence, the use of life cycle assessments can represent qualities of frugal innovations. The use of life cycle assessment in the design process is only one attribute to be utilized in the design process. The iteration of several LCA on new design ideas and alternative products is used. The evaluation using LCA on products will help determine what areas needed redesigning and alternative ideas in materials, processing and transport and be extracted and substituted from other designs. The next step in the frugal design model will be iteration of LCA. The model states four iterations. Nevertheless, the number is subjective to the complexity and limitations of alterations presented by each LCA.

The indicators utilized in an evaluation of frugal innovations are general indicators that can me specified to each product. The general rule of LCA indicators is to reduce the waste in all areas, benefit individual's lives and create a profit for locals. The indicators depicted can give insight to general areas in need of improvements without limiting the design process with product details allowing for the application of the design process to all products, frugal or otherwise.

The understanding of qualities and functions of various indicators is vital for understanding the model, however for a specific application weight may be utilize. Weight of LCA helps determine tradeoffs that may arise from several situations with in the product development. However, the weighting scale of LCA is dependent on the individuals developing the product. The indicators depicted are not assigned specific weights but must be know to have an influence on the design. The weights can be determined using various tools such as multi criteria analysis. Weighting also provides qualitative measuring data for comparison between different products. The comparison between the three pillars and their effects are different and constant a portion of subjectivity, but this does not mean it is completely random. Methods of weight range from multi decision making for the final product selection to EPS2000d.

The application of multiple-criteria decision making (MCDA) takes into consideration many aspects of the product. The tool allows for the designers to determine which qualities discovered through research is more important than others. Cost has high importance in frugal innovation designs, along with environmentally responsibility. However the cost of being environmental responsible is commonly higher then of not being. The qualities of frugal innovation are beneficial to one another however at times one quality may be detrimental to another. The use of MCDA will be used along with a weight scale ranging fro 0 to 10. Zero being the least important and a rating of ten is considered very important. The designers will determine what the value of each quality is for every product design. The weighting scale is extremely subjective and involves suggestions from the voice of the customer. The use of MCDA is applied in the final understanding of the LCA evaluations. The numbers given by the LCA are to determine the impact the product has on the three pillars. These numbers can have half hard facts and half biased due the designers and customer influence. Therefore a weighting

scale is needed to determine what qualities are important while some may be less important for the end goal of a sustainable frugally innovated product.

7.4.1 Stage 1: Initial Analysis

The aim of this is to conduct a LCA study on specific life cycles and life stages of product ideas. To accomplish this, a definition of the proposed product and the structure of development are needed. Execution of life cycle inventory of the components of the product described in previous chapters is required.

As a result of this stage we get a profile of the product being evaluated in units of social, environmental, and cost obtained in the LCAs based on the standards of frugal innovation.

7.4.2 Stage 2: Generation of Alternatives

This stage utilizes the LCA to enhance the product or give alternative choices to the design. To complete this stage we need all the social, cost, and environmental information about the product along with the same information about alternative materials, processes, and customers. The designer must perform the same life cycle assessment to the alternatives. This will give areas where alternative materials or processes can be substituted to have a lower impact on all the LCAs.

7.4.3 Stage 3: Analyses of Alternatives

The new alternatives to designs are developed into new products. This stage utilizes the

same process of analyzing with each LCA to obtain evaluations of each pillar. This step is similar to the process of Stage 1 however, evaluating the new alternatives. The new alternatives have scores of E-LCA, SLCA and LCA and will be utilized in Step 4 to determine the final product.

7.4.4 STAGE 4: SELECTION OF PRODUCT DESIGN

The combination of the three LCAs and comparison of all alternatives will give an optimal product to determine which is the most frugal innovated product out of all the designs. The four stages will give a rapid solution in discovering the optimal frugally innovated product intended to solve the problem or assist the individuals in need.

The use of three LCA methodologies described above enables the designer to propose an integrated model that incorporates social, environmental, and economic markers creating a sustainable product. The final combination of the three LCAs will present an optimal frugally innovated product that can be developed and incorporated into the market.

The use of environmental, social and economic life cycle assessments presents a new and unique way to develop a design. The design focuses on aspects portent to frugal innovation and providing opportunity to optimize the product using various alternatives throughout the life cycle of the product. The design of the product can be evaluated as many times deemed necessary. However, the utilization of LCA will reduce the cost of creating a product through a conventional style and find flaws while being tested in select markets and groups. LCA will provide new insight to incorporate sustainability to designing but particularly in designing fugal

innovation.

7.5 Development of a Frugal Innovated Product

Development of a product is the last step of the frugal innovated design process. This step utilizes all the information in the previous steps and applies it to the development of the product. If problems arise, the frugal innovated design process can be reassessed. The information and design will allocate into this step providing a smooth transition into the manufacturing of the frugally innovated product.

The design model described is new in its approach in combining voice of the customer and life cycle assessment in developing a bottom of the economic pyramid product. This approach can be instilled in academic and research and development settings to help allocate the frugal innovation into new areas.

CHAPTER 8: CASE STUDY TREADLE PUMP

This chapter presents a case study of the frugal design model methodology. The treadle pump is a water delivery pump developed in Bangladesh, (Chigerwe, Manjengwa, Van der Zaag, Zhakata, & Rockström, 2004). Intensive research was conducted regarding development of the treadle pump, however access to the targeted environment is extremely limited. Third party sources gathered information regarding the manner in which the product was designed and processed. The following section is a brief history and the utilization of my frugal innovated design model to enhance the innovating process. This case study will support the frugal innovated design model in the development of a successful frugal innovation.

8.1 Product background

In 1976 Gunnar Barnes was given an opportunity to create a product to provide irrigation water to local farmers in Bangladesh. The criteria gathered from local farmer interviews required the pump be able to irrigate at least 0.5 ha of land and the total cost of purchase, and installation was not to be more than the price of one bag of paddy. One bag of paddy is estimated to be 1,300 Rubes ($26) and the pump was to be simple enough to make and repair locally, (Lambert & Faulkner, 1991). These criteria of design was not included thus leaving an opportunity to create a new product in all aspects.

The treadle pump's operating principle is based on suction to lift water from a low water source. The treadle pump uses two cylinder chambers and pistons to create a suction to draw water up a shaft along with a check relieve value to prevent back flow. One or two individuals can operate the treadle pump by simultaneously stepping on it, as one would step on a stair master. The capability of allowing two people to operate the pump increases the volume of water discharged. The design of the treadle pump was evidently cost effective at $20 per unit in 1988. The original design was developed for hand pumps, however, with innovation and observation the pumped evolved to irrigate large farmland areas. The alteration in design from arms and hand power to legs and feet was conceptualized in that by utilizing larger muscles a more efficient and less exertion would be achieved by the operators. The use of leg power increased the amount of force, therefore, creating a larger quantity of water. This understanding did not occur over night, yet when discovered, the acceptance and popularity became contagiously successful. The success of the treadle pump was not only in the design but also due to the utilization of local manufactures, since previous pumps were imported from outside the country. Designers had to educate manufactures how to construct the treadle pump by providing the design, material list, and tools needed for producing the pump. The treadle pumps can be manufactured in common workshops found in Bangladesh and around the world if given proper training and tools.

The distribution of the treadle pump is commercially profitable business rather than donations from government agencies allowing the treadle pump to prosper for decades. The economics application to the treadle pump helps make a sustainable product benefiting all involved in it's developing, manufacturing, and distribution transactions. With the use of local

distribution networks along with informed manufactures, wholesalers, retailers, and customers, the treadle pump has become a successful product,(Joseph & Yamikani, 2011).

The impacts of the treadle pump are easily viewed as socially beneficial. It has enabled local farmers to increase the amount of land that can be irrigated and reduced work time compared to conventional delivery of water, which was previously done by carrying buckets of water or using a low flow hand pump. The larger volume of water improves crop quality, reduces irrigation periods, and increases growing cycles because crops grow faster and healthier when water is applied abundantly (Chigerwe et al., 2004).

The treadle pump has a positive economic and social impact on the people themselves. The increased crop yields provide more profits for farmers. The entire supply chain was affected positively by increase sales and therefore creating more employment in all areas of delivery. The environmental impact is not obviously seen through open observation. However, the treadle pump does have a positive environmental impact by being sparing of materials and reducing transportation distances, i.e. reducing carbon dioxide expulsion. The pump utilizes renewable energy, human power rather than electricity or diesel utilized by conventional pumps.

Prior to the treadle pump, the cost of buying, running, and maintaining conventional pumping systems for irrigation, limited farmers in developing nations to thrive. This was the only effective manner but limited funded farmers only manner to irrigate was by renting diesel pumps, (Palmer-Jones & Jackson, 1997). However, the cost of running and renting was still out of reach for the majority of famers. The use of manpower delivery water systems rendered

operational with buckets and hand pumps, which both provided inadequate amounts of water and was labor intensive. However, treadle pumps revolutionized the irrigating process by supplying a much needed and desired solution for many frugal farmers in developing nations.

8.2 How the treadle pump was developed

The Rower Pump, a hand powered pump that utilized a single piston similar to a bicycle air pump design inspired the treadle pump, (Palmer-Jones & Jackson, 1997). The designers of the treadle pump understood that the people of Bangladesh were attempting to irrigate their lands with this pump. The hand pump was designed to provide water to a family home usage not irrigation of large lands. The designers experimented with various prototypes of hand pumps to determine maximum levels of efficiency and water product. They all fell short to providing large volumes of water efficiently. The designers understood the Rower pump utilized a single pump and cylinder to create a suction to pull up the water. Garner attempted to utilize two pistons, except the increased effort was strenuous for arm and hand power, (Chigerwe et al., 2004). The next step was to transform the pump into a leg and foot operated device since those muscles are larger and can exert more force. The next obstacle was to determine the size of the well. The notion bigger is better, was incorrect. The primary well sizes were one and a half inch piping. Nonetheless, customers reduced the piping size to one inch. The decrease in well size was optimal for the treadle pump stroke motion. This stroke movement and well size provided more volume of water with each stroke of the pump. The one inch was a much more efficient diameter along with using leg power rather then arms. The treadle pump design was developed. The next step was to determine the materials to construct the pump; the original design was entirely made of metal making it a robust product. This was unpopular since the need for

locality was essential to incorporate the treadle pump to Bangladesh. The use of local materials such as bamboo wood was substituted however the piston and cylinder needed to provide a seal therefore metal was still used for this segment. The manufacturing responsibility of the pistons, cylinders and arms was given to local workshops. By providing them with a design blue print, tools and quality control checks, the treadle pump became a locally developed and desired product for farmers. The entire process of the treadle pump was time consuming not only in the design but also in the marketing of the pump to villages. Farmers in the area had low literacy rates so brochures and instructions could not be in a word format but in pictures depicting the benefits and use of the treadle pump, (Chigerwe et al., 2004).

The focus of this case study will be about the application of Life Cycle Assessment to increase the efficiency of the design process. The design process and acceptance of the treadle pump around the world took more than 8 years, (Chigerwe et al., 2004). Factors involved are numerous, although, the process of determining the optimal product was conducted with trial and error. The notion of frugal innovations was not dramatically known. The formation of a pump that is inexpensive, assists a society and is environmentally considerate was still developed. The process was time consuming because of many unknown factors that had to be taken into consideration to create an optimal frugally innovated product. This final product was developed and is still sustainable in developing nations. If the design process of frugal innovation that incorporates Life Cycle Assessments was utilized, the treadle pump would have been created more efficiently.

8.3 Application of Design Process of Treadle Pump

The treadle pump is a product that has been classified as a frugal innovation. However, the steps and method of the development was conceived using common design process and voice of the customer. The following information has been observed and applied by the inventor; however, the treadle pump information will be applied to a frugal innovated approach of development to hypothesized and give an example on the application. The hypothesis of the case study application to the designing process and model formulated will give an accelerated manner in creating a frugal innovation that is sustainable. The data presented was gathered from various sources describing the needs and manner the treadle pump was developed. The following is a basic application of the frugal innovation design model to create the treadle pump. This will demonstrate that the design process is plausible in creating a sustainable product that has dramatic positive impacts on a developing nation.

The first step is to define the problem. In this case individual farmers had land 0.5 Ha in size, which needed to be irrigated. The common process of irrigation was flood irrigation. Flood irrigation is the process of flooding the entire land and immersing the land in less than one inch of water. This process utilizes large quantities of water, 30,000 gallons of water is necessary for 0.5 Ha of land, (Chigerwe et al., 2004).

The treadle pump focus points were to solve a common problem found by farmers in India. The problem was to flood irrigate an average farm plot, .5 Hectares, with the minimal amount of energy with maximum rates of delivery. The product must be capable of operation by all members of a family; this includes children, women and men. The products purpose is to

transport water from a well or other water sources ranging from 5 feet to 25 feet vertical height, since the water table was no deeper then 25 feet. The cost of a product was set at 1,300 rubes this was determined by farmers' wiliness and ability to pay.

The following is a list of questions and answers for a practical application and formation of a frugally innovated product. The questions are broad questions that focus on water delivery to farmland in India. The answers have been discovered by previous explanations of the treadle pump.

Define the problem: Inadequate manner of providing water to Indian farmland,0.5Ha.

Voice of the customer are various questions to get insight on what is needed and wanted by the targeted group, farmers of India. The following questions and answers were obtained through interviews and geographic data reports obtained by treadle pump creators. The following are questions I believe are important in understanding the extent of the needs of the farmers of India in order of determining a proper product.

Voice Of the Customer:

- Q. What will the pump be used for?
  A. To efficiently pull water up from a water source below 25ft
- Q. How often will the pump be used?
  A. Watering twice a month.
- Q. What is the operation duration of the pump?
  A. The amount of time to irrigate 0.5 Ha dependent on operators input.

- Q. What is the environment (weather) the pump will be used at?
  A. Humid and hot

- Q. What energy is available and what is the cost?
  A. Manpower, liquid combustible energy (diesel)

- Q. Who will use the pump?
  A. All individuals, children, women, and men.

- Q. What are the skill sets of the individuals?
  A. Low skill sets

- Q. What is the educational level of the customers?
  A. Low education, low literacy

- Q. What is the physical standing of customers operating the pump?
  A. Good physical standing capable of walking and working

8.3.2 BRAINSTORMING:

The second step to formulate a frugal innovation will be to utilize the information gathered from customers and statistical information available of the targeted area being India. The following are general data and questions to be answered for this case study. However, for an extensive research and application of frugal innovation much more detail and questions related to the defined problem will be explored. The information discovered will be presented to a group of individuals that are included in the brainstorming exercises. The individuals vary from product to product explained in the frugal innovation design process.

Information about resources is important to understand, for the materials in the production of the product. The skill level is essential for the treadle pump, in order to manufacture a simple but precise equipment in local markets to keep the price as low as possible. An evaluation of the environment is needed to understand the conditions the product will be

enduring. The last two suggested data to obtain is price and completion. Price acceptance was determined by questioning the customers and comparing products that are currently being utilized for the same problem.

Determine available resources.
A. Forests and high levels of ground water

Determine skill level of the work force.
A. Specific skills of workers; ironsmith, workshops, manufactures

Evaluate the environment.
A. Tropical monsoon-type, hot rainy summer and dry winter, temps average 26 Celsius

Acceptable price.
A. no more than a bag of paddy (1,300 Rubes)

Similar products available.
A. Gas power suction pumps, windmills, hand pumps, solar pumps

8.4 Criteria and Specification Constraints:

This section is to provide constraints to give guidance to the designers on specifications the pump should have. The constraint of user centric and ruggedness eliminates solar pumps. Solar pumps are complicated to install, maintain, and are delicate in the humid environment.

8.4.1 EVALUATION:

The evaluation will take in consideration satisfaction of social needs, product durability, contribution to GDP, fair prices, material recyclability, material and energy intensity, and water usage. The life cycle assessment of the product uses select matrices and indicators specific for frugal innovation. The measurement of the indicators are the work/energy used in operation, the cost in rubes of the finished product, the locality of the delivery of the pumps, the warranty

length of the product, the gallons per minute the pump produces, and the amount of total water achieved.

The chosen matrices were by availability of data that was present without utilizing an LCA program to provide specific details on all aspects. A LCA program will give the entire life cycle and measurements of specifics allowing for a proper assessment. While the assessment in this case study is simple, a clear understanding demonstrates aspects from the three alternatives can be utilized in the treadle pump. The evaluation and observation of simple inputs from the three choices helps bring to life the treadle pump.

Understanding the *Material and Energy Intensities* of the three products shows the amount of energy needed to operate the product. The suction pump uses electricity at a rate of one Kilowatt for every hour. This eliminates this option because there does not exist a reliable electrical power source in the rural areas of Bangladesh. The windmill uses wind power. This is free energy but is inconsistent to provide water during specific times when needed. The hand pump is manually operated, providing no cost in operation and gives the opportunity to operate at any hours. The evaluation determines that manual power is the optimal option.

Fair prices of the product were stated to be at or less then 1,300 Rubes. The amount allows farmers to purchase the product. The suction pump has a cost of 11,000 rubes exceeding the cost minimum, along with the extreme cost of windmills at 270,000 rubes. The hand pump is optimal cost of 540 rubes, since it is a simple device with the least amount of moving parts and materials.

The contribution of the gross domestic product demonstrates how the product provides economic assistance to a nation. The manufacturing and materials of all the products are produced in China and other nations. This provides minimal contribution to the GDP, however local venders of the products are affected positively since they sell the products to farmers.

The *durability* of the products is measured through the duration of warranty guaranteed by the manufactures. The need for a durable product reduces the cost over a period of time. If a product has a short life span, farmers will have to purchase the product over and over again. The products warranty varies between products, although compared to the cost of the product the farmers will never make a return in investment except on the hand pump.

Satisfaction of social needs is measured by the output of water generated by the pumps. The amount of water acquired is a social need for more water creates more crops thus creating more profit for the farmer. The measurement is gallons per minute, the out put of a suction pump is at 35 thus extremely efficient and capable of irrigating 0.5 Ha in less then 8 hours. The windmill is capable of irrigating in 12 hours. However, the hand pump is at 10 gallons per minute thus taking days of hard labor to irrigate a field, (Lambert & Faulkner, 1991).

The last input is *water usage*, measured in the total amount of water used. The common goal found out by VOC was to flood irrigate a field. The required amount is 30,000 gallons in all areas.

A designer can observe from this simple evaluation what qualities are efficient and needed in an optimal frugally innovated product. The use of manual power and low cost qualities can be used from the hand pump. The high amount of water obtained from suction pumps and windmill is needed. All products do not utilize local networks reducing the contribution to GDP. The last matrix of water usage can be seen in the environmental checklist. This evaluation gave rise to adapting the current treadle pump but with a new approach. Utilizing the treadle pump for suctioning water but reducing the outlet, creating pressure. Instead of farmers using flood irrigation, the treadle pump attached to an output hose can create pressure for the utilization of sprinklers for efficient and less water consuming process then flood irrigation. Sprinklers have been seen to reduce evaporation rates and have a direct application to crops rather then loss through soil seepage. If a comprehensive study was done on the three pumps, other aspects may be observed and utilized. Rather, this case study is solely meant to explain how the design process is implemented.

Indicators

1. Material and Energy Intensity
2. Fair Prices
3. Contribution to GDP
4. Product Durability
5. Satisfaction of Social Needs
6. Water usage

	Sution Pump	Hand Pump	Wind Mill	Treadle Pump
1. Work	1 kw/hr	manual	wind	manual
2. 1,300 Rubes	11,000	540	270,000	1,100
3. Delievery supply	LV	LV	LV	LV, LM, LL
4. Warranty	2	30	5	3
5. Gallons per Min	35	10	25	25
6. Total Gallons	30,000	30,000	30,000	30,000

Figure 16: Treadle Pump LCA

Treadle pump											
Environmental Issue	**Stages of the life cycle**										**All stages**
	Acquisition		**Production**		**Use**			**End-of-Life**			
	Raw materials and energy	**Pre-manu-factured materials & components**	**Production**	**Packaging**	**Use**	**Maintenance and repair**	**Use of additional products**	**Reuse/ Material and Energy Recovery**	**Incineration without energy recovery**	**Final disposal**	**Transportation**
Inputs											
Materials					Wood						
Water					30,000						
Energy					0						
Land					.5ha						
Outputs											
Emissions to air											
Discharges to water					30,000						
Discharges to soil											
Waste					Loss due to evaporation						
Noise, vibration, radiation, heat											
Other relevant aspects											
Risk to the environ-ment from accidents or uninten-ded use											
Customer information											

Figure 17: Environmental Checklist

CHAPTER 9: DISCUSSION

9.1 Discussion

This dissertation has elucidated the characteristics of frugal innovation and presented a practical guide for applying the principles and lessons discussed. Frugal innovation (FI) is a powerful and ultimately essential approach for developing products in emerging markets. Frugal innovation is the answer to developing new technology in an environment with limited resources. Financial, material, or infrastructure resources are used as strengths. Discoveries of novel techniques maximize efficiency in developmental, production, and delivery systems. Frugal innovations contain qualities of being low cost, green, and markedly competitive with comparable products developed through current design processes.

Contrary to popular belief, products deemed frugally innovated are stigmatized as being low quality and low-tech. However, a frugal innovation creates products uniquely and utilizes the most recent technology. Frugal innovation is not bounded by design restrictions, but rather intently looks to redesign the developmental process. The frugal mindset is not merely low-cost engineering but an overarching philosophy of utilizing new methodologies and ideologies in product design. The formation of this concept came about with exposure of foreign nations' technological influences and a need to survive in a developing setting.

9.2 The Origin of Frugal Innovation

In discovering the origin of frugal innovation it can be concluded that India and Brazil have many similarities. Within both nations there is a large gap between the rich and the poor. A missing middle class creates a strain on government programs that provide basic needs to their people. Brazil and India both demonstrate two separate large classes of rich and poor. The poverty in both nations requires rudiments such as clean water, access to food, shelter, and health care. The demand for frugal innovation is understood to be a method in providing these needs, however, the necessity does not explain the formation of innovation.

The second characteristic shared between the two nations is demographics. The aging populations in both nations have similar literacy rates and mortality rates. These indicators describe the populations as a whole, which require large amounts of resources to sustain itself. A large population along with an increasing growth rate causes an escalation in poverty, thereby straining the nation's resources. However, demographics do not explain the cause of frugal innovations being created.

The third area of research was directed towards educational aspects in India compared to that of Brazil. Innovations require knowledge in order to formulate solutions. Hence, educational institutions are the focal point of knowledge. One would think the educational systems would provide tools in developing innovations. Yet, it is not found to be true in these countries. India and Brazil lag in the academia spectrum and in general public education. The average adult receives five years of formal education within India and Brazil. In both nations, there are lags in publications and patents, due to the lack of government funding. Education is

the basis of inventions and innovations in the western nations. However, it is proven unnecessary for the development of frugal innovations in India.

The last information collected was pertaining to the nation's economic status. India and Brazil are categorized as developing nations with low-income citizens. However, the assistance provided by domestic governmental approaches serve well in India compared to Brazil. India stimulates business growth by promoting simplistic loan obtainment for their citizens. The low cost of labor, resources, and taxation creates a desirable environment for foreign nations to establish businesses in India. Corporations use India as a stepping stool to manufacture and produce goods to sell around the world. Hence, with the acceptance of technological trade and knowledge, India is exposed to alternative solutions. Brazil, however, hinders the promotion of foreign and domestic business success due to national regulation; this prevents the sharing of ideas. I believe this is the reason why India is the birthplace of frugal innovation. Social combinations where the majority of their citizens are in poverty, the need of basic necessities, and an exposure of frontier technology, provide a breeding ground of frugal innovations. Indian citizens share similar problems and help each other to generate plausible solutions. In conclusion, this brings to light why frugal innovations are discovered in India and are predominantly focused in providing the essentials for survival.

9.3 Frugal Design Process Model

A well-documented systematic process for developing a frugally innovative product is currently non-existent. Therefore, I developed a model to help make decisions in creating

complex frugal innovations into a simplified process. Models are known to be successful if users have a clear understanding of the goal, as well as have access to a template to guide them. The model I developed does not specify details for designing a specific product. However, a model that focuses on the matrix is much more beneficial. The design process incorporates various methodologies along with a similar outline seen in current product developmental processes. T The model contains constraints pertinent to the frugal innovation mentality, discovered through numerous literatures, and studies reviews. Frugal innovations have been discovered not to focus solely on a single pillar of sustainability but rather utilize aspects from separate pillars to benefit one another. Constraints of frugal innovation are established throughout the process, beginning with design boundaries and restrictions. Frugal innovative products must be rugged and able to withstand environmental abuse such as rain, dust, and vibrations. However, these qualities are difficult to quantify and apply to all applications. A designer must focus on achieving these qualities that are essential in frugal designs. The primary goal of frugal innovation is to create a product that is inexpensive to operate and affordable to all people who need it. The last goal is to create an efficient product by reducing unnecessary waste in resources and energy thus passing along the savings to users. The integration of lower energy and resources provides an environmental benefit, through the reduction of green house gases and pollution released into the atmosphere and biosphere.

Frugal innovation's fundamental method of solving problems has been discovered to be trial and error in order to provide the best product. However, trial and error methods are expensive and unorganized. The use of social, environmental, and cost life cycle assessments provides an alternative method in determining the optimal product.

The rational behind creating a design process model is to give individuals in academia or industry research access to a blueprint that develops frugally innovated products. Design processes are the basis of understanding and applying methods to develop products in educational courses. It would seem only right to include a similar methodology towards the development of frugally innovated products.

9.4 Implications which Positively Affect the Pillars

Sustainable issues are emerging as one of the major driving forces for change in our world. Product and design processes need to respect the environmental, social, and economic limitations. The frugal innovation process incorporates the three pillars as constraints that lead to the discovery of improved performing products. Life Cycle Assessments (LCA) is a systematic tool that quantifies the environmental impacts of products and services. LCAs provide advantages in the decision making process, leading to win-win situations towards sustainability. To conduct a proper assessment on products and processes requires total life cycle information. Sustainable concerns are identified early in product design in order to effectively and economically resolve problems. LCA studies are utilized as tools in aiding decision-making. Frugal innovation benefits profit margins, energy savings, and social assistance. Societies have become accustom in consuming resources as if they were unlimited. Unfortunately, there is a finite amount of natural resources. Humanity must utilize resources in a responsible manner so future generations will not bear the burden of our negative effects.

Frugal innovated products are designed with sustainability in its DNA, and not merely having an agenda of sustainability. The development and application of frugally innovated products directly and indirectly, affect the three pillars of sustainability in a beneficial aspect. Frugal innovation's known characteristics directly affect the environment by sparing materials and energy. These qualities lower cost of operation and allow the customer to allocate their funds elsewhere. Simultaneously, businesses create large profits by selling high volumes of products.

Frugal innovations are a web of interactions between the three pillars of sustainability. Contrary to current design processes, frugal innovation utilizes positive features in one pillar to assist other legs of sustainability in a productive and unforeseen manner. Frugal innovations emphasize the needs of society by providing a simple solution to essential necessities such as health care, water, food, and shelter. Frugal innovation is not a win-win (social-economic) situation as described in the literature; however, it's a win-win-win (social-economic-environmental) situation. Current societies' hunger goes unfulfilled, due to limited understanding and education. All the while, environment conservation must be sustained in order to help people thrive and gain profits, for frugal innovative design is the small but essential step to change the focus in creating a sustainable society.

9.4.1 LIMITATIONS

Current understanding of frugal innovation is in its infancy stage. The literature is limited to the implications of what frugally innovated products are, however a clear observation is seen throughout this dissertation that frugal innovation is sustainable. The understanding of

why India is the focal point of frugal innovations has shed some light on the topic and a process for developing and managing a design is developed in this dissertation.

9.5 Future Work

This dissertation is general on the approach of understanding the differences between two nations. Future work may include a deeper look and acquisition of data pertaining to a real-time observation of the frugal innovation process. Markers may be included such as trade, workforce age and types, or educational systems from adolescence to the university may be focused on.

Future work regarding the design process, a case study utilizing the process to create a newly innovated frugal product or a case study and surveys to relate the design process to an existing product my be done. Furthermore, future work may add or eliminate steps from my proposed design process.

Frugal innovation is hypothesized to be sustainable by the ways it interacts with the pillars but a more in-depth research and application of total LCA can further clarify the results from cradle to the grave for frugal innovation. Frugal innovation designs are unfamiliar to designers in the western world but said to be essential to developing countries for survival. This concept is concluded to be a sustainable product design that will make companies and individuals aware of sustainable designs.

9.6 Conclusion

Compared to current designs, frugally innovated products can increase in value by reducing environmental impacts, costs, and increasing positive social impacts while maximizing profits for manufacturers. Frugal innovations are viewed only through finished products, nevertheless engineering based structured guidelines were unavailable to direct frugal innovators in the developmental processes, until now. The understanding of where and how frugal innovations originated, gives way to a design process model for the application in new settings. Products that are developed under frugal innovation standards, methods, and tools can be implemented from start to finalization of a product's development process.

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