Sustainable Architecture Design: Environmental and Economic Benefits

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A Senior Thesis submitted in partial fulfillment
of the requirements for graduation
in the Honors Program
Liberty University
Spring 2016

Acceptance of Senior Honors Thesis

This Senior Honors Thesis is accepted in partial fulfillment of the requirements for graduation from the Honors Program of Liberty University.

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Abstract

This thesis examines the movement of environmentalism, and its impact on architecture and construction. During an interview with a professional architect, a basis for research of sustainable design was devised, when he explained that "good" architecture attempts to holistically integrate the external and built environment. Presently, the main measurement for sustainability is energy efficiency. Therefore, architects constantly implement new technology in an attempt to unify both the external and built environment in an energy efficient manner. Furthermore, this thesis provides an environmental and financial cost analysis of implementing sustainable design and build. Research shows that the life cycle and up-front costs are the most important considerations for the construction industry. If the operational costs and up-front costs can be decreased, sustainable build may become a more attractive business venture. In conclusion, expectations would be that as sustainable construction technology continues to be refined, the momentum of the environmental movement and economies of scale will cause sustainable construction to become more attainable.

Sustainable Architecture Design: Environmental and Economic Benefits

Architecture is the combination of art and design for the construction of a building project (Hersey, 2008). The aesthetics and design should work together to create holistically beautiful buildings. American architect Frank Lloyd Wright articulately emphasized, “The mother art is architecture. Without an architecture of our own we have no soul of our own civilization” (Fichner-Rathus, 2016, p. 225). In this high form of art numerous people are daily affected by redesigning the natural conditions of a setting through buildings, parks, and memorials, possibly even without their recognition. This thesis will specifically focus on the design aspect of architecture, attempting to supply further information for sustainable design and build. Moore (2015) provided another definition of architecture, “the interaction of man and nature through the utilization of the built environment” (Personal communication). He also explained that all construction must be conscious of its immediate environment, meaning *good* architecture will integrate the external and built environment. Therefore, when an architect creates a building, the two environments interact with one another, attempting to balance three different elements: function, appearance, and durability. Furthermore because art, including architecture, reflects the values and ideals of the current society, the methodology concerning the application of the three elements will change according to the culture and times (Hersey, 2008, p. 610). Overall, this thesis will analyze the societal benefits, specifically environmental and financial, of the current movement of sustainable design.

History of Environmentalism and Architecture

Greater environmental awareness has been a consequence of the present movement of environmentalism, which has caused key societal changes that have changed the field of architecture. As Fieldson (2004) states, "architecture has closely reflected the period of development of environmentalism since the 1960s" (p. 24). It is necessary to understand the historical formation of a movement, which determines its essential objectives and furthermore the impact it will have on society.

The mainstream environmentalist movement began within the North American region after the 1973 OPEC oil crisis caused a significant decrease in the supply of oil, producing gas shortages and causing prices to skyrocket. Because gas directly affects a majority of humans with motorized transportation, awareness of the potential over-dependency on nonrenewable energy increased, which evolved environmentalism "from an ideology into a full-fledged social movement" (Siliviera, 2004, p. 497). Therefore, environmentalism gained momentum and began to have many sociological consequences. Some of the notable successes for the environmental movement are the Wilderness Act of 1965, the Clean Air Act of 1976, National Trails Act of 1968, the Wild and Scenic Rivers Act of 1968, and Earth Day 1970: "By the late 1960s, activists began to link the destruction of the natural environment to the complex interplay of new technology, industry, political power, and economic power" (Siliviera, 2004, pp. 505-506). In attempt to combat perceived environmental destruction, activists began to raise awareness in and utilize these spheres of influence, specifically technology, industry, and economics.

Prior to the formation of environmentalist movement, primitive architecture would maximize functional sustainable design, attempting to increase function while using basic resources. For example, instead of air conditioning, natural air ventilation would be utilized to naturally cool a home. However, the environmental problem increased with the introduction of energy-consuming technology, specifically household electricity. Through the use of household utilities and appliances, buildings can accomplish similar internal comfort through greater energy consumption, causing potential negative effects on the external environment (Moore, 2015, personal communication). For instance, artificial light, air-conditioning, heated water, and electrical appliances are a small number of the technological advances that consume energy (Cowan, 1976). Furthermore, the combination of household technology and increase in personal households has led to increasing levels of energy consumption. Because the environmentalism movement ideologically views the poor use of energy as a problem, the movement's idea about energy efficiency and conservation began to permeate into the construction industry.

One outcome from combination of environmentalism and the construction industry was the U.S. Green Building Council (USGBC), which is a non-profit organization that was founded in 1993 for the purpose of cultivating the idea that "our built environment should nurture instead of harm, restore instead of consume, and save money instead of waste it" (Dimeo, 2009, p. 1). As a non-governmental organization, USGBC had to gain influence without the use of official government policies. "[Its] robust network of members (individuals and organizations), chapters, advocates, professionals and students" allows USGBC to exercise governance of sustainable construction throughout the entire industry (Ludwig, 2013, p. 43). Its most influential entity has become Leadership in Energy & Environmental Design (LEED), which was initially launched in 2000. LEED is essentially an accreditation program that certifies specified sustainable attributes of buildings, which encompasses “the entire lifecycle of the building, from design and construction to operations and maintenance, and include[s] virtually all types of built structures, with special requirements and criteria for certain types of buildings” (Ludwig, 2013, p. 53). The ceritification process is completed by a USGBC affiliate, the Green Building Certification Institute (GBCI), which eventually grants or declines accreditation to the construction project. If a building becomes LEED-certified, then it has been verified as “having lower operating costs through reduced waste, energy and water usage, improving the health and safety occupants, reducing generation of polluting greenhouse gases, and qualifying for a range for a range of public incentives,” which promotes positive environmental, social, economic changes (Ludwig, 2013, p. 54). Historically, the LEED campaign has been successful at raising sustainable design within the construction industry. In 2015, it was estimated that between 40 and 48 percent of “new nonresidential construction will be green” (McGraw-Hill Construction, 2010, p. 1). Furthermore, based on research collected by the USGBC, the overall amount of industry-wide square footage pursuing LEED certification is continuing to rise (U.S. Green Building Council, 2015). The effects of the environmentalist movement, specifically the formation of the USGBC, on the architecture and construction industries are clearly evident.

In many ways, the movement of sustainable architecture has attempted to renormalize the interaction between the built and external environments. The essential means has been through continually striving toward increasing energy efficiency, offering a continuously progressive objective for the environmental movement (Young, Da Rosa, & Lapointe, 2011). The concept of continually increasing energy efficiency can be summarized by the word sustainability, which is a societal ideology that meets its own needs without hindering the needs of the future (Kwong, 2010). Furthermore, as McLennan (2004) states, “sustainable design is a design philosophy that seeks to maximize the quality of the built environment, while minimizing or eliminating negative impact to the natural environment” (p. 79). If sustainable design is a philosophy, then it can be mirrored in any design process, including architecture.

Effect of Environmentalism on Modern Architecture

Environmentalism has birthed an architectural philosophy, sustainable design, which has created energy-focused solutions, such as energy efficient technology. McLennan (2004) essentially states that this philosophy demands an expansion of the traditional definition of architecture. The delicate balance of design elements should not only include function, appearance, and durability but also humanity and the environment. The foundation of this philosophy builds upon two basic beliefs. First is universal lack of respect—the current lifestyle of society has a negative impact on the environment, which puts the existence of all life on the planet at risk. Therefore, the notion of universal respect for the environment could solve these issues. Second is universal responsibility—due to the negative environmental impact, responsibility must be assumed and changes must be made to ensure creation its continued existence. By starting with the presupposition of disrespect, supporters of sustainable design believe the current human impact on the environment is negative and a reason for concern. But, precisely this concern causes them to focus on and solve the problem of environmental disrespect, which, according to McLennan, can be resolved through the philosophy of sustainability.

Sustainable design solutions directly flow from the notions of respect and responsibility. Based in the philosophy's presuppositions, followers of sustainable design should respect the environment and take responsibility for any effects caused by human interaction. First, respect will be evident in the design process, which will consider the positive and negative environmental effects of every design project. Second, responsibility is dutifully managing the outcome of a situation. Therefore, a sustainable designer must have a sense responsibility for all design factors from start to finish. Otherwise, the responsible designer could neglect portions of a project, causing ill effects to factors deemed "outside of his/her control." Using the presuppositions, McLennan (2004) further broke down a set of sustainable design principles. First, he shares the principle of "respect for the wisdom of natural systems," which is best defined by the concept of biomimicry (p. 35). Through expounding the word *biomimicry* into biological mimicry, the simplicity of this principle is evident—design can be improved through imitating the design of nature (p. 44). Second is "respect for people – the human vitality principle" (p. 45). With a human-focus, design is filtered through the essential concept that ultimately architecture is designing a habitat for humans, and therefore the livelihood of humans needs to be considered throughout the process. Third, "respect for place – [the] ecosystem principle" gathers design ideas and building materials from the unique location of each building (pp. 52-53). Fourth, "respect for the cycle of life," which is a principle rooted in a responsibility of long-term cause and effect and was formerly referenced (p. 64). Fifth, "respect for energy and natural resources – the conservation principle" is based in the belief that "we live in a finite world but treat our resources like they are infinite" (p. 74). So logically from the perspective of an environmentalist philosophy, the finite resources need to be used in a sustainable manner. Lastly, a "respect for process – the holistic thinking principle" is a trickle down approach to environmental activism. It is based in the concept of "if we want to change a result, we must first change the process that led to the result" (p. 86). In other words, good and heavily implemented sustainable design will return environmentalists' end goals.

In connection to sustainable design principles, if energy consumption continues to be coupled with depleting nonrenewable energy sources, the environmental movement will directly oppose this negligence (Marques & Loureiro, 2013). Because environmentalist thought is deeply aware of human impact on the environment, the objective has become creating the most effective method of collection and utilization of energy. By striving for this objective, the mindset of environmentalism and advances in technology has produced a potential solution through the means of renewable energy to combat depleting nonrenewable energy. Theories of harvesting renewable energy have always existed, but advances in technology have materialized these ideas (Pimentel, D., Herz, M., Glickstein, M., et al., 2002).

Active Sustainable Design Processes

Active sustainable design processes are methods of capturing energy from naturally renewable sources, such as the sun, wind, or water. As stated, the development of these processes is due to the rise of societal awareness in energy efficiency and concerns of pollution. Awareness may have recently risen, but human fascination with the natural sources of power is historically evident, for example, many ancient religions worshipped the sun through gods manifested in its character—Apollo, Re, and Sol—and also utilized its various assets—sundial, calendars, and astrology. According to

McClennan (2004), all of the fanfare is not misplaced. Much of our human progress literally revolves around the sun:

> In some way or another, almost all the energy that is available on the earth comes from the sun, or came from the sun at one time. The warm temperature that sustains all life on the earth comes from the sun in the form of electromagnetic radiation. Our atmosphere has been designed beautifully to keep enough of this heat on the earth's surface rather than scattering it back out into the universe as it does in all the other planets and moons in our solar system. (p. 74)

With modern active sustainable design innovations, perhaps Thomas Edison correctly prophesied when he said, "I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that" (Newton, J. D., & Mazal Holocaust Collection, 1987, p. 31). In *Philosophy of Sustainable Design*, McLennan (2004) lists numerous examples of old and new technologies that increase the energy efficiency of the built environment. Still, active design processes do not guarantee energy efficiency, because the behavior of the user ultimately determines the amount of energy used. Still, by harvesting energy through renewable resources, a less negative impact on the environment is intentioned.

For the purposes of this study, only a simple narrative of the science of renewable energy production is necessary—but for further study of the science of electricity, solar power, and aeropower readers can reference *Homebrew wind power* by Bartman & Fink (2009) and also the *Handbook of Photovoltaic Science and Engineering by* Gray, Hegedus, and Luque (2011). To quickly summarize the science of active sustainable energy, the sun radiates energy toward the earth, which is captured by the atmosphere, initiating the energy transfer process. Then the earth reacts to the energy received, creating different methods to capture these energy sources (p. 74; Bartmann & Fink, 2009, p. 49).

Although other forms of energy are still produced in greater quantities, renewable energy sources, such as solar power and aeropower, have begun to contribute a small amount toward the energy market. The U.S. Energy Information Administration, EIA (2012), states that the 2011 annual production in quadrillion British thermal units (Btu) of each equals: natural gas 23.506, coal 22.181, crude oil 11.986 nuclear 8.259, hydroelectricity 3.171, wind 1.168, geothermal .226, and solar/photovoltaic .158, which evidences that the major energy providers are nonrenewable energy sources. However, the data from EIA evidences a trend toward increased renewable energy production from 2010 to 2011, specifically Appendix A respectively shows a 147% and 81% change in wind and solar energy production (Energy Information Administration, 2012). In contrast, the data shows a -5% and -2% change in coal and nuclear energy production, which may signify a global trend toward renewable energy sources (EIA, 2012). Currently, it should be noted that oil production is at record highs, which affects the production of all energy sources. However, oil industry analysts state that these levels of production cannot be sustained, which should result in normal energy production trends once again (Energy Information Administration, 2016).

Still energy efficiency, the main concern of sustainable design, is a vital factor. Although solar power and aeropower are not yet mainstream energy producers, the energy efficiency of both continues to improve. Because electricity is the vital source of power throughout homes, the electric conversion efficiency of the above sources is important to the study of sustainable design. In 2003, Eureloectric measured the efficiency of electricity generation in power plants of various energy sources. The average maximum energy efficiency generation are as follows: hydropower plant 90%, coal fired 45%, steam-turbine fuel-oil 45%, wind turbine 42%, nuclear power 41%, photovoltaic cells 15% (Eurelectric, 2003). Although in 2003 the solar power and aeropower were less efficient than many of the other options, present researchers state that the conversion performance ratio (efficiency) of solar power for "well-designed installations varies from .7(70%) to .8 (80%)" (Gray, Hegedus, & Luque, 2011, p. 7). In addition, Bartmann and Fink (2009) state that aeropower turbines are approaching the Betz limit of 59.26% for energy extraction and conversion. Therefore, based on the potential trend toward renewable energy sources and the increasing efficiency of these devices, sustainable design should continue to utilize and innovate the active renewable energy technology.

Passive Sustainable Design Behavior and Processes

Prior to listing different design options, one must understand that an important key to decreasing energy consumption is a mentality of conservation, which can be explained as making a conscious attempt to reduce the amount of energy consumed. Reducing energy consumption is a dual mandate of energy efficiency and minimalist behavior. Ideally through these practices, one could continually strive for maximum efficiency and minimum energy consumption, but this is a personal decision for each consumer. As Shen, Cui, and Fu (2015) explain, the personality of a person will influence energy conservation decisions. The authors list six different personalities: effective altruistic, socially outgoing, easy-going, adaptive, traditional, and extremely resolute believer. Shen, Cui, and Fu (2015) empirically expound upon the results from a study, by Allcott (2011), of social norms and energy conservation. In Allcott's observation, the energy company OPOWER successfully reduced energy consumption through a community-wide initiative. All members of the community received a personal letter regarding neighborhood energy conservation metrics, which discreetly provided a conservation benchmark to each member of the community, specifically the rate of the top percentile of energy conservers. However, Shen, Cui, and Fu (2015) observed a boomerang effect among participants. Although consumers would often decrease energy consumption, there was a tendency to return to normal consumption patterns. Therefore, their study analyzes conservation behavior, attempting to "understand the dynamics of energy behavior change so as to develop a new normative feedback mechanism for building energy conservation" (p. 324). Using the data, the generated model analyzed the effects of the personalized benchmark message on each different consumer personality. According to the research, the message produced the desired effect, tempering the boomerang effect of energy conservation. Therefore, the model theoretically provides evidence that consumer behavior can be influenced to reduce energy consumption. The purpose of both the prior studies was to influence behavior of the consumers, which emphasizes the importance of personal decision-making in changing public matters. Because a mindset of conservation does not necessarily require any financial investment, the decision to reduce energy consumption can be the first decision of sustainable design implementation.

Often neglected but equally viable are passive sustainable design options. Focusing on sustainability has caused sustainable designers to adopt energy efficient practices. For example, the use of energy efficient devices, embodied energy reduction, and durable building life cycles are all passive design options that lead to environmental and financial benefits. In attempt to reduce energy consumption, passive design methods will often manipulate the external environment to save or collect energy. Furthermore, McLennan (2004) states that passive sustainable design does not neglect comfort, a fundamental of architecture. Instead, it utilizes the new "strategies, components and technologies that lower environmental impact while creating comfort and overall quality" (p. 7).

First, purposeful landscape can passively reduce the need to residentially consume energy. Dumitras suggests a variety of versatile methods that can be implemented. First, solar and wind protection can be provided through the placement of trees, wall climbing plants, pergolas, and shrubbery near the building. The design should also be effective in varying external environmental conditions, specifically due to the changing seasons and weather. Therefore, each aspect of the landscape should be adjustable to maintain energy efficiency. Fortunately, residents can use the natural landscaping cycle of growth and dormancy to combat the changes of energy provision in different seasons (Dumitras, 2013). Furthermore, construction design can passively increase energy efficiency as well. In Iran, the most advantageous method of renewable energy is considered to be passive solar energy. Through increasing surface area, improving thermal storage and resistance, and applying glazing, windows can become more energy efficient and better resist intense energy from the sun. Also, by increasing the slope of the roof, buildings would be able to better passively utilize solar energy (Heravi & Qaemi, 2013).

Another concept considered in sustainable design and construction is the embodied energy of building materials, which is equated through the sum of energy required for the production of materials, energy necessary for the transportation of materials, and also energy required for assembly of the project materials (Reddy & Jagadish, 2003). Because the objective of sustainable construction is energy efficiency, each construction project will also strive for the minimum amount of embodied energy still completing the customer's desired deliverables. Wood reportedly has the lowest production energy consumption followed respectively by lime-pozolanna (LP) cement, limestone, cement, steel, glass, and then aluminum. Furthermore, in consideration of energy consumption during transportation, due to the ability to travel lesser distances, closer proximity of materials has a positive correlation with energy savings. Still, the method of transportation should also be considered, utilizing the most fuel-efficient vehicle (Reddy & Jagadish, 2003).

As stated, deliverables must be provided to correctly complete work and provide customer satisfaction. Two common deliverables for many construction projects are durability and minimal financial costs. Rarely will these deliverables be forsaken for the sake of sustainability. However, sustainable design can optimize durability and savings, which permits the three concepts to simultaneously be achieved. First, a durable will remain useful for a long time. Therefore, from a sustainability standpoint, the building should be relatively energy efficient to retain its usefulness. Researchers measure durability through calculating the building life cycle, which is the sum of the building's operational and embodied energy. The operational energy is the amount of energy required to operate a building, and the embodied energy is the amount of energy already expended to construct and operate the building. Therefore, when one decides to develop real estate, life cycle energy analysis should be considered. If an old building is present, then the questions of how much energy is already embodied and how much energy will be required to operate the building are relevant. Because destruction of an old building will discard the energy consumed during its original assembly, it is possible that recycling the building materials or renovation may be a better option. However, if the old building is energy inefficient or no prior building exists, then new construction only has to consider the future embodied and operational energy expended (Fay, Treloar & Iyer-Reniga, 2000).

As mentioned, demolition of a building can be wasteful misuse of the embodied energy linked to construction materials. Dahlbo et al. (2015) proposed a solution to mitigate wasteful misuse of resources through construction and demolition waste (C&DW) management, which recollects reusable materials and energy from construction or demolition projects. There are three main forms of C&DW management: recycling, energy recovery, and landfilling, the foremost process proving to be the best environmental performer (Michaud et al., 2010). However, general principles of economics are still major barriers to universal implementation of C&DW, such as the "high availability and low cost of virgin raw materials" (p. 334). The central purpose of the Dahlbo et al. study is to analyze the EU Waste Framework Directive (EUWFD) that targets a 70% recycling of non-hazardous C&DW by 2020. Gathering data from the EU nation of Finland, the researchers were able to determine the average percentage of materials gathered from the typical state of C&DW management, totaling wood at 36%, mineral at 35%, metal at 13.5%, and other materials at 15.5%. Although projections show that the EUWFD 70% recycling objective will not be met in Finland, sustainable design can utilize the potential environmental and economic benefits of C&DW management, which includes three crucial components separation efficiency, energy efficiency, and cost effectiveness.

Dahlbo et al. (2015) discovered that there are two steps of C&DW separation management: initial separation and secondary separation. The initial separation efficiency measured metals highest followed by wood, concrete & materials, and other materials—see Appendix B. Excluding concrete & mineral and other materials, the secondary separation is near perfect efficiency. In another study, Yuan et al. (2013) made progress in further developing the C&DW process, finding that on-site sorting of materials greatly increased the resource reuse and recycling efficiency, decreasing the amount of C&DW entering landfills, which is environmentally beneficial. The researchers also realized that energy efficiency and cost effectiveness are interrelated. If operations are more energy efficient, then costs will decrease and vice versa, which is economically beneficial. Therefore, energy efficiency, or energy recovery as Dahlbo et. al. (2015) define, is an important factor of C&DW management, and sensibly understanding that greater conservation rather than greater consumption should be desired from an environmental and economical perspective.

Dahlbo et. al. (2015) determined that all forms of C&DW management had positive inflows of energy efficiency. Overall, however, wood had the most energy efficient waste management process. Although concrete and mineral accounted for the greatest amount of the recovered materials, the positive energy inflow was minimal. Unfortunately, these materials also had the worst energy efficiency, causing the process to be cost ineffective, which means that labor must be utilized for a difficult job that is minimally beneficial (p. 338). In addition, because concrete and mineral, the material that is most frequently recycled, is environmentally and economically cost ineffective, progress still needs to be made in the efforts of C&DW management before it is a sustainable economic option (p. 340).

Economic Analysis of Sustainable Design

Due to the immense number of factors impacting the environment, it is difficult to quantify the environmental benefits of sustainable design. However, energy consumption and efficiency provides a suitable metric of measurement not only for environmental analysis but also for financial calculations. Therefore, implementing sustainable design can have direct environmental and monetary benefits (Pearce, 2008).

Niu, Ding, Niu, Li, and Luo (2011) study the connection between national energy consumption and national economic growth, more specifically the direct correlation between these concepts. The study examines the question of whether economic growth causes energy consumption or vice versa. A plethora of studies from 1978 to 2010 have shown mixed results in answering this question. However, the authors noticed a trend in the studies and differentiate between two groups of countries, developed and developing countries. The study is designed to analyze eight countries in the Asian-Pacific region—Australia, Japan, New Zealand, South Korea, China, Indonesia, Thailand, and India. Categorization of the countries is based on the economic statistics of Appendix C, which provides insight into the population, GDP, and energy production and consumption metrics. It can be assumed that economic trend analysis and the use of these metrics provide the distinction between developed (Australia, Japan, New Zealand, South Korea) and developing (China, Indonesia, Thailand, and India) countries. In observation, the authors found that the energy intensity (kg/dollar) of developed countries was significantly smaller, which is understandable based on the societal technological advances that typically improve energy efficiency.

In proper context of this study, the main purpose is to address the topic of climate change. Perhaps, larger collective energy consumption of developed countries results in an increased amount the carbon dioxide emissions are also increased per capita. However, for the purpose of sustainable design research, the connection between growth of GDP, energy consumption, and energy efficiency is equally important. As the authors state, "energy is the material basis for human existence" (Niu, Ding, Niu, Li, & Luo, 2011, p. 2123). Therefore, although energy consumption may negatively impact the environment, developing countries should not neglect the use of energy to exist and fuel economic growth. Instead, the authors recommend an alternative, stating that all countries should have a conservation mindset while consuming energy. This policy would also permit a period of overconsumption for developing countries to achieve economic progress.

Many clients avoid sustainable design because it has been associated with increased capital costs. However, according to the research of Dobson, Sourini, Sesrtyesilisik, and Tunstall (2013), sustainable construction is directly connected to a more energy efficient building. All projects have a breakeven point; sustainable project investors can calculate two forms of breakeven analysis: financial and energy use. Financial breakeven point is met when the fixed and variable project costs equals the profits of a project. The energy breakeven point is met when energy consumption from construction and operations equals the energy savings from the new sustainable design, further integrating the prior concept of life cycle analysis. The researchers referenced the example of a new school construction project, which projected the energy efficiency received. The new sustainable design method would be 300% more energy efficient (Dobson, Sourani, Sertyesilisik, Tunstall, 2013). Another study by Thompson and Yealdhaul (2010) provides a corporate strategy to implement a cyclical process of energy efficient processes. From 2004 to 2008 EnergyWorks' central utility plant (CUP), the research subject, planned a plant wide protocol following three specific objectives 1) selective equipment upgrades, 2) automation of best practices in operations & management, and 3) designing and installing an energy management system for real-time optimization. These steps allowed CUP to realize a 75% electrical consumption reduction. Although the data from both examples is insufficient to calculate a breakeven point, increases in energy efficiency directly decrease variable costs, which will result in meeting the breakeven and gaining positive returns. Therefore, based on breakeven analysis, both hypothetical and literal sustainable projects have proven to be economically beneficial.

The common concern with sustainable construction projects is the high up-front costs. As mentioned, all projects have an energy and cost breakeven point. If the initial costs are higher, then the breakeven point is also higher and more difficult to reach. Therefore, all project stakeholders will attempt minimize the initial fixed costs. Pearce (2008) provides a number of recommendations to decrease the fixed costs of sustainable design implementation. First, the sustainable design should "solve the right problem" (p. 295). She suggests that this method requires a change in mindset. Instead of asking the question "how can one finance a new building," the question should address the ultimate need for the building. For example, if the objective for a new building is a place of residence for employees, the design can be stripped of any unnecessary items and focus on being a home, improving the deliverable and the bottom line. Next, Pearce (2008) recommends optimizing every aspect of the project, essentially utilizing the ideal amount of resources and time through creative methods of resource, cost, and time management. Because project management best practice already attempts to utilize every avenue for cost savings, optimization cannot solely be attributed to sustainable design projects. Still, these cost savings methods run parallel to ideology of conservation from sustainable design philosophy, which offers monetary and energy savings.

If sustainable design can continue to become more financially enticing, then the demand for these design characteristics will likely increase. Dobson, Sourani, Sertyesilisik, and Tunstall (2013) recommend a number of different methods to enhance the supply and demand for sustainable construction. First, stricter government legislation could be put in place. By enforcing new building standards, the construction industry would be required to implement specific energy efficient design. However, the same goal has been accomplished through a privatized system, the USGBC. This council has created the LEED certification, which has compiled a list of sustainable building specifications. If sustainable projects are built to meet LEED standards, then the USGBC can be financially reimbursed to categorize and certify a building as sustainable, verifying the design solutions as meeting certain environmental requirements (Ludwig, 2013). Second, if greater care is attributed to the design process, then potentially a more cost effective sustainable solution could be offered. Third, if competition is increased between the sustainable material manufacturers, then greater economies of scale would occur and cost would decrease. Fourth, if more construction work implemented a greater amount of sustainable design, then the awareness of sustainable construction would increase, which in turn could increase demand for said products (Dobson, Sourani, Sertyesilisik, Tunstall, 2013). If any of these methods increases the demand for sustainable design, then economics states that the supply for sustainable design will increase as well. From a basic economic analysis, as supply increases, the price decreases. Therefore, if the environmentalist movement continues to gain advocates, then sustainable design will likely increase not only in architecture but also in machines and consumer goods.

Conclusion

The current analysis of sustainable design and architecture provides insight into multiple facets of the sustainable architecture and design: historical background, philosophy, practical application, and economic. Each of these aspects must be considered for the viability of sustainable design practice. Historically, environmentalist thought has recently had a large impact on public policy and sentiment. One of the environmentalists' key areas of focus, energy efficiency has become a mutual chief goal across all industries. Furthermore, the impact of the environmentalist movement equally affected the fields of architecture and construction, eventually resulting in two systems for sustainable design—a governing organization and a philosophy. First, the USGBC is a non-profit organization that implicitly governs environmental problems within the construction industry. Its most successful means of creating environmental change has been through LEED certification, which verifies the legitimacy sustainable design additions of a construction project. Second, the formation of a philosophy has created a set of guidelines for designers to reflect upon and abide by during the practice of architectural design. Although this thesis has projected energy efficiency as one of the chief goals of sustainable philosophy, potentially leaving the source of fuel as irrelevant, the energy industry has dramatically transformed into a multi-faceted industry, forming non-renewable and renewable energy entities. Some of the active sources of renewable energy have advanced technologically, including solar power and aeropower. However, the passive sources of renewable energy are equally important to the process of sustainability. If a designer can increase energy efficiency through passive measures, then the principles of sustainable design are also achieved. Furthermore, because sustainability originates with the mindset of conservation, many of the methods of passive sustainable design focus on improving energy consumption or prevention of gain/loss of energy. Fortunately for the consumer, the sustainable design process can be economically beneficial long-term. Some of these processes have high up-front costs, however if the sustainable resources function correctly, the energy consumption savings will allow the investment to breakeven at a given payback period, which addresses the main concern of this thesis. Based on the compiled research, sustainable architectural design does result in feasible environmental and economic benefits, which should result in future sustainable innovations within the construction industry

Although this thesis only briefly studies the future path of sustainable design, if the current trends of the energy and architectural sectors continue, then the methodology of sustainable design will continue to become integrated into current design processes. Further analysis should be done to project the future of sustainable design. Also, as further information arises about the economic aspects of sustainable design, research should continue to be conducted to determine if the intended effects of implemented sustainable design have been accomplished and also if further innovations of sustainability will be environmentally and economically beneficial.

Appendix A

Primary Energy Production by Source (Energy Information Administration, 2012, p. 7)

Energy Production (Quadrillion Btu)

		Coal	Crude Oil	Nuclear	Solar/PV	Wind
2007		23.493	10.721	8.455	0.076	0.341
2008		23.851	10.509	8.427	0.089	0.546
	2007-2008 Δ%	2%	-2%	0%	17%	60%
2009		21.624	11.348	8.356	0.098	0.721
	2008-2009 Δ%	-9%	8%	-1%	10%	32%
2010		22.038	11.593	8.434	0.126	0.923
	2009-2010 Δ%	2%	2%	1%	29%	28%
2011		22.181	11.986	8.259	0.158	1.168
	2010-2011 Δ%	1%	3%	-2%	25%	27%
	Average Total Δ%	**-5%**	**12%**	**-2%**	**81%**	**147%**

Appendix B

C&DW Management Separation Efficiencies (Dahlbo et al., 2015, p. 337)

Table 2
Separation efficiencies of the source separation (for overall C&DW) and treatment lines for the material inputs produced by source separation.

Material	Share of the material separated from overall C&DW at generation sites (%)	Separation efficiency of the specific treatment line for the material fraction from source separation			
		Metal treatment (%)	Concrete & mineral treatment (%)	Wood treatment (%)	Miscellaneous treatment (%)
Metals (Fe, Cu, Al)	75	100	100	100	100
Concrete & mineral	70	0	99.5	0	86[a]
Wood	71	0	0	100	100[b]
Other[c]	50	0	0	0	82[a]

[a] Including fines that are utilised at landfills.
[b] A share of wood fraction ends up in the SRF fraction.
[c] Includes SRF and all other materials such as glass, plastics, ground/dirt.

Appendix C

Asia-Pacific Demographics & Energy Statistics (Niu, Ding, Niu, Li, and Luo, 2011, p. 2124)

Energy, economic and carbon emissions profiles of the eight Asia-Pacific countries.

Index	AUS	JPN	NZL	KOR	CHN	INDO	THA	INDI
Area (10^4 km^2)	769.2	37.784	26.868	9.9	960	190.44	51.31	298
Population, total (10^6, 2008)	21.02	127.77	4.28	49.053	1328	225.63	65.44	1186.2
GDP (current 10^{10}\$, 2008)	101.52	490.93	13.069	92.912	432.62	51.439	26.069	21.75
Per capita GDP (current \$, 2007)	39091	34314	32073	19984	2428.4	1918.3	3843.8	1047.7
Energy production (million *t*, 2005)	25551	3795	920	14911	36665	23753	39563	1423
Energy intensity (kg/dollar)	19.386	10.824	15.861	27.369	73.511	54.728	42.728	46.418
Per capita energy use (*t*, 2007)	5.861	4.037	4.208	2.372	1.411	0.523	1.347	0.364
Per capita CO_2 emissions (*t*, 2005)	18.086	9.6267	7.244	9.394	4.2553	1.9024	4.2997	1.281

Notes: unit of energy *t* is oil equivalent. AUS—Australia, JPN—Japan, NZL—New Zealand, KOR—South Korea, CHN—China, IDNO—Indonesia, THA—Thailand and INDI—India.

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