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Material Sustainability

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SUSTAINABLE & GREEN BUILDING

To be able to address the concept of Green Building, a conclusive definition of Sustainability and green is required. The definition of sustainability is a process or state that can be maintained at a certain level indefinitely. Broadly, this can spread across social, economic and environmental dimensions. As the concept of sustainability has grown more prevalent, it has set a common goal to meet the needs of the present without compromising the ability for future generations to meet their own needs.

"The term **Green Building** refers to the quality and characteristics of the actual structure created using the principles and methodologies of sustainable construction. Similarly, **Green Design** describes the application of sustainability principles to building design. **Sustainability** is the foundational principle underlying various efforts to ensure a decent quality of life for future generations."
– Charles J. Kibert

In the terms of Engineering and Building Construction, sustainability is a broad design philosophy in which focus is driven towards minimizing the overall impact of the built environment on the natural environment and human health. By efficiently using water, energy, and natural resources, the environmental impact is minimized. Human health is protected and enhanced by providing safe, productive living and working environments. And most importantly, by reducing pollution, waste and environmental degradation, the natural environment is protected and preserved for future generations.

'Going green' is a term that is quickly spreading across the world over many industries and professions. The concept of Green Building has drastically changed the way that construction and design is approached from the very beginning stages of any project. Through new techniques and practices, designers are able to directly focus their attention to areas that can minimize, and ultimately eliminate the damaging impact that buildings generate. Green Building has proven itself as an environmental benefit, as well as an economical means of design that is both cost effective at the time of construction, and throughout the entire life span of the building.

WHY DO WE CARE?

To be able to work towards sustainable design and be motivated about new innovations, it is important that we understand why building green is so important. In the last few years, it has been obvious that the world is becoming more aware of green-house gases, depleting natural resources, waste production, and energy consumption. What is often neglected is how much of this is caused by the construction, operation, and disposal of buildings. While there is some variation, there is general agreement that 50% of material resources taken from nature are building-related, over 50% of national waste production comes from the building sector, and 40% of the world's energy along with 13.6% of all potable water is consumed by buildings (Anink, Boonstra, Mak, 2004). The EPA estimated that in one year, 136 million tons of building-related debris and 22% of total stream waste was generated from construction and demolition (USGBC). Almost 50% of worldwide carbon dioxide emissions are produced primarily by the construction and operation of buildings, and the production of cement alone produced 8% of the total CO_2 emissions in 2000 (Kang and Kren, 2007).

Obviously, these effects on the local and global environment cannot be neglected. The entire life cycle and impending impact of a product needs to be taken into serious consideration when designing a building. Recently, there has been a great deal of evidence that service life predictions are inaccurate, or by any means the buildings are not withstanding as expected. In Sweden, 25% of buildings that have been demolished since 1980 were less than 30 years old. Similarly, in Tokyo, the average lifetime of buildings has dropped to 17 years (Berge, 2009). It is important to analyze and fully understand what is included in the extraction phase of raw materials, the production phase, the building phase, and the decomposition phase – so that each person involved in the design and construction process can make educated decisions and work towards a fully sustainable model.

LEED

Green Building is not a very new concept, but the demands of our society have drastically catapulted this design approach to a level of necessity. In general, designers have always consciously chosen materials or building plans that have minimal environmental impact. In this day and age though, it plays such an important role in the building sector that it is necessary to have a framework to measure a building's energy levels, environmental impact and long term sustainability. In 1994, Robert K. Watson, senior specialist of Natural Resources Defense Council, began the development of the Leadership in Energy and Environmental Design (LEED). The U.S. Green Building Council (USGBC) fully developed LEED into a Green Building rating system that plays a crucial part in most building development across the United States today. The LEED rating system is built upon six main categories: energy saving, water efficiency, CO_2 emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts (USGBC). LEED uses a point system to accredit buildings on their practical use of green design, construction, operations, and maintenance where applicable in the six different categories. A building going through certification can acquire up to 69 points which places the building into one of four LEED categories. The levels are Certified (26-32 points), Silver (33-38 points), Gold (39-51 points), and Platinum (52-69 points). To date, over 5 billion square feet of commercial building space is involved with the LEED system, but out of 19,524 projects that are registered, only 2,476 of these projects have completed the certification process (USGBC).

Having a LEED accredited professional on a design team counts as an additional point towards that building's LEED compliance (Cotton, 2007). The majority of professionals that hold a LEED accreditation are Architects, not Engineers or Contractors. In fact, per the latest USGBC LEED Directory, less than 1% of LEED Professionals are Structural Engineers. Jeff Gatlin, a Mechanical Engineer with Thompson Engineering, has his LEED designation, but feels that most people "who want LEED certification get close, then see what is involved and [they] back off " (Cotton, 2007).

Not only are professionals hesitant to achieve their designation, but some owners are very timid to pursue LEED accreditation because of the assumption that additional costs will be accrued through the certification process. Gatlin agrees that additional costs may vary and that it can add up to 10% to the final cost (Cotton, 2007). What is important to focus on is the life cycle savings of the building, as well as environmental benefits. These financial benefits are accumulated by lower energy, lower operational and maintenance costs, as well as waste and water costs (Milligan, 2001). Recognizing the hesitation towards 'going green', many local governments are creating LEED incentive programs to help persuade owners and designers to build sustainably. Some of these programs include tax breaks, density bonuses, government grants, and low interest loans (USGBC). With proper education in the benefits of Green Building and with the support of local governments, professionals can begin to see past the initial cost and focus on designing for the necessary means of sustainability.

MATERIALS:

Due to the fact that construction and disposal of buildings have such a detrimental impact on the environment and natural resources, it is imperative that we approach solutions from every angle. Despite Green Building being such an important concept, the LEED rating system is often only addressed by the architectural field. Architects play an obvious role in terms of flow through the building, energy usage, and environmental impact – but not in terms of the structural material used at the core of the building. For green design to be properly practiced, it is important that structural engineers do not limit themselves to the latter half of the project, when they should be involved with the early conceptualization of the building. It should be the role of the Structural Engineer to justify the proper use of a certain building material in terms of the long term implications and sustainability.

By addressing all sides of design at the early stages, the project can be more proficient in terms of sustainable solutions, as well as addressing design conflicts before they arise. It is also important that engineers do not rely simply on "overdesigning" – the concept of Green Building emphasizes that increasing materials and strength, from what has been found to be adequate, is not necessary and may be detrimental to the overall design. Every professional involved with the design or construction of a building should be well educated in the terms of Green Building, and should view their position as an essential portal to create the most sustainable building possible from all aspects (Wood, 2007). The role of the structural engineer is an integral part in terms of the selection of materials, use and application of structural systems, and the focus on future adaptability of the buildings (Kang et al. 2007).

The following document will highlight and address the implications involved in the initial material selection, by focusing on the use of Concrete, Timber, and Steel.

CONCRETE:

The Concrete Society's Materials Group recognizes that concrete is the "premier construction material across the world and the most widely used for providing essential infrastructure for transport, industry, and commerce and habitation/human shelter" (The Concrete Society's Materials Group, 2001). With this being said, concrete does not bring many benefits to Green Building. One of the few benefits that concrete brings to a LEED building is its high heat capacity. Concrete can act as a stabilizer to a building, in terms of maintaining a constant internal temperature and reducing high fluctuations in heat from occupants, lighting, and sunlight (The Concrete Society's Materials

Group, 2001). Aside from this benefit, concrete requires a very large amount of energy to create and install, which has many longstanding negative effects on the environment

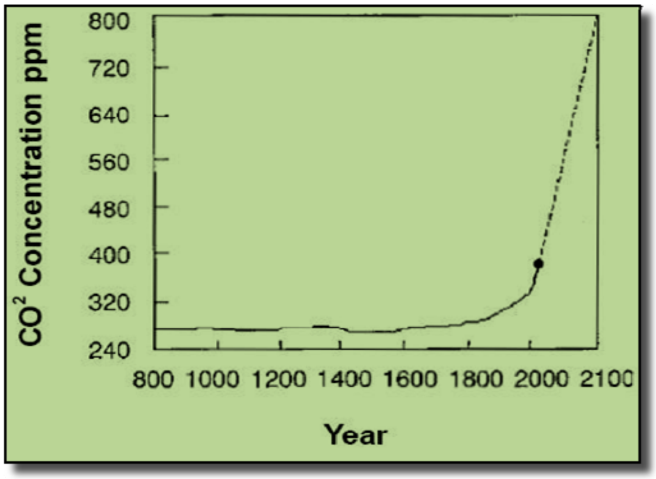

Figure 1: Historical and future atmospheric CO_2 concentrations as associated with the production of concrete. Source: Mehta, 2001

Portland cement is one of the main components of concrete; it acts like the glue to hold all the materials together. The process of making Portland cement requires large quantities of coal or petroleum coke to heat limestone or chalk to high temperatures of almost 300 degrees Fahrenheit (The Concrete Society's Materials Group, 2001). During this process, carbon dioxide is produced by the reaction between shale and limestone. Along with the cement releasing CO_2, the energy and fuel required to run the kiln also creates gaseous waste in the form of CO_2 (Struble & Godfrey). It is estimated that for each ton of cement that is produced, an equal amount of carbon dioxide is released into the atmosphere. The production of cement alone makes up 5% of the global greenhouse gas emission created by human activities (Russell, 2009). Not only does the manufacturing of concrete create large amounts of greenhouse gases, but it also consumes significant amounts of fuel and energy. The entire process of acquiring virgin materials, batching, mixing, and transporting makes concrete the most energy intensive building material used today (Mehta, 2001). An analysis showing the estimated increase of CO_2 concentration is shown in Figure 1.

In addition to greenhouse gases being produced by the manufacturing of concrete, there is also waste that is accumulated along the way. The principal waste created by concrete production is dust, unused concrete, and contaminated wash water. For every gallon of water used in the mixture of concrete, a gallon of water goes to waste to wash out the truck after transportation (Struble & Godfrey). At the end of a concrete building's life cycle, the demolition will generally leave nothing but waste as well. Sometimes, demolished concrete may be down-cycled in a pavement sub base – but to date the concept of recycling concrete is not common in the United States (Struble & Godfrey).

When working with concrete, it is also imperative that we focus on its durability and strength, as acquired through the construction phase. P. Kumar Mehta [2] believes that the "fast-paced construction world has broken down the craftsmanship that goes into concrete structures." Though the strength of concrete has continued to increase over the years, as seen in Figure 2, this is not necessarily beneficial in terms of fundamental material science, where Mehta is concerned with the "close connection between cracking and durability" (Mehta & Burrows, 2001). This is a key issue in terms of sustainable design, in which cracking in concrete exposes steel to the environment, leading to structural deterioration. The strength of a building's materials is meaningless if it is not constructed properly, and in return handicaps the building's life cycle. In common construction, concrete buildings are designed for 50 years of serviceable life. In many coastal environments and urban cities, we have found that concrete buildings are deteriorating in only 20 to 30 years (Mehta, 2001).

Because concrete plays such an integral role in our society in terms of construction, it would be difficult to justify its environmental impact as a reason to completely shut down its production and use. Concrete is used among a wide variety of applications, including buildings, highways, and foundations. In 2006 alone, over 14 billion cubic yards of concrete were produced. These large production levels are why we must come up with solutions as to minimize concrete's negative impacts and use it as sustainably as possible. The concrete industry has recognized this issue, and they have invested heavily in research to find ways to make concrete a beneficial material for green building.

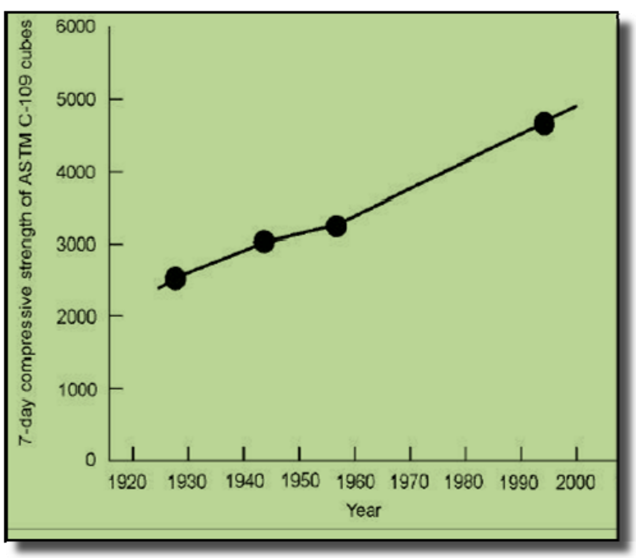

Figure 2: Increase in the 7-day strength of ASTM type 1 Portland Cement, produced in the USA during the last 70 years. Source: Mehta and burrows, 2001

One important change that has occurred in concrete is the exercise of systems recycling and re-using water at production plants. By re-using water, not only are operating costs reduced, but the large amounts of pollution released to nearby streams and waterways are also reduced. The concrete industry is one of the largest consumers of fresh water – and with only 3% of Earth's water being fresh, it is crucial for the concrete industry to not only efficiently use water, but avoid any further contamination (The Concrete Society's Materials Group, 2001). The average amount of fresh water used in production is 500 gallons per truck per day. By reserving the contaminated water in ponds, the water is able to separate from the composites. This water can then be recycled back for the plant's use, or can flow out to another body of water (Building Green, 1993).

Another significant change that has taken place in building construction is the use of fly ash. Fly ash is a deposit that comes from the combustion of coal in power plants, and can be used in place of cement in the production of concrete. Research shows that 600 million tons of fly ash is generated each year worldwide with 80% disposed of in landfills (Russell, 2009). Not only is fly ash concrete a great way to use waste material, it also has remarkable material properties that improve strength and durability, and has been found to improve the interfacial zone of concrete. Bradford Russell[3] has researched green materials and has found data that shows the "enhanced mechanical properties [of fly ash concrete] include higher elastic modulus, lower shrinkage and creep, excellent freeze-and-thawing resistance, lower water permeability, and lower chloride-ion penetration" (Russell, 2009). Replacing a percentage of cement with fly ash is also beneficial to water conservation. Water is such an important ingredient in concrete because it plasticizes the cement into a workable paste, but fly ash requires less water to reach the same satisfactory consistency. Mehta has found that depending on the quality of fly ash and the amount used to replace cement can decrease the amount of water used by 20%. So in a sense, fly ash acts as a super plasticizing admixture – and in return improves the concrete further by reducing the drying shrinkage. The process of replacing about 20% of cement with fly ash in a concrete mixture can really enhance the sustainable quality of the concrete industry by creating a long-lasting product. Figure 3 shows a sample fly-ash mixture recipe.

In addition to the use of Fly Ash, there has been research along the lines of using bamboo in place of steel for concrete reinforcing. One reason for using bamboo is its strength to weight ratio is twice that of steel, which can be very beneficial where weight is critical in construction (Russell, 2009). The other reason for using bamboo is its natural sustainable qualities that are becoming better known among the world of construction and design. The natural properties possessed by bamboo give it good reason to be used in light construction where we would normally see steel reinforcing.

Type I portland cement	Class F fly ash	Water	Crushed calcareous sand	Crushed basalt rock (25mm max size)	Super-plasticizer
106 kg/m^3 (180 lb/yd^3)	142 kg/m^3 (240 lb/yd^3)	100 kg/m^3 (170 lb/yd^3)	944 kg/m^3 (1600 lb/yd^3)	1120 kg/m^3 (1900 lb/yd^3)	3.5 L/m^3 (90 oz/yd^3)

Figure 3: A sample table proportions for a crack-resistance, high-volume fly ash concrete. Source: Mehta, 2001

When dealing with concrete, it is important to provide an overall analysis of the life cycle. A lot can be accounted for when focus is directed towards the bigger picture. MSCG concludes that "a more durable concrete may require higher cement content, but the structure will have a longer working life and require less maintenance" (The Concrete Society's Materials Group, 2001). All in all, the process of recycling water from power plants, using Fly Ash concrete, and integrating bamboo is incredibly beneficial to the environment. Until we find a better alternative to concrete in construction, these solutions should be implemented in the use of sustainable construction where applicable.

TIMBER:

Timber is a very environmentally benign material when it comes to greenhouse gases, air and water pollution, and energy use; the typical life of a timber member is shown in Figure 4. As a natural resource, Timber has great benefits over steel and concrete in terms of energy, renewability and gas emissions. In manufacturing, construction, demolition, and reuse, steel has been found to use 140% more energy and create 1900% more water pollution than timber. Likewise, concrete has been found to produce 81% more greenhouse gases and 96% more solid waste than timber. Engineered Wood Association shows that wood products make up 47% of all industrial raw materials, but consume only 4% of the total energy used to manufacture all industrial raw materials (Sullivan & Horwitz-Bennett, 2009). By simply looking over timber construction, it would appear that it should be the sustainable material of choice, but timber is simply not as strong as concrete or steel and is a daily depleting resource.

The general definition for sustainability is the assumption that the process being implemented can be done indefinitely, and timber is a resource that will not be harvestable indefinitely. Forty-two million acres of tropical forests were cleared in 1990, an increase of 40% from 1980. The American Institute of Architects (AIA) predicts that all tropical forests could be depleted by the end of the 21st century (Sullivan et al., 2009). This has a grave affect on the construction industry, and therefore the implementation for using Sustainable Timber is very important. When we speak of Sustainable Timber, it means that for every tree that is harvested, another tree is planted to replace it. This replacement is not only important to assure that there is timber for construction, but it also maintains the ecological demands in terms of climate, water control and biodiversity. Sustainable timber also refers to the involvement of locals, and their benefits from the forest and long term income. Horwitz-Bennett, from Building Design Construction, says that, "More than 200 million acres of forestland in the U.S. alone are certified as sustainable and responsibly managed, attributable to four main forest certification programs in the North America." These programs are the Forest Stewardship Council, The Sustainable Forestry Initiative, The American Tree Farm System, and the Sustainable Forest Management Program.

Another timber solution is the use of Reclaimed Wood or "rediscovered" wood. The Rainforest Alliance defines Reclaimed Wood to come from demolition projects, dead or fallen trees, reclaimed wood from demolition landfills, and wood by-products from secondary manufacturers (Sullivan et al., 2009). The use of reclaimed wood has obvious benefits; for example, reduced material costs, low environmental impact, and offers a green marketing advantage. On the other hand, being able to construct with reclaimed wood requires a large amount of labor in terms of proper deconstruction, de-nailing structural members, and then additional cleaning and trimming required – which can leave the structural members too small to use for future construction. In some circumstances, it may be cheaper and easier to simply use new timber instead. A few studies have been completed on the cost comparison of deconstruction versus demolition, but a thorough analysis has yet to be published. The cost of deconstruction must include the savings of disposal costs, but the labor involved in each task adds up quickly (Sherman, 1998).

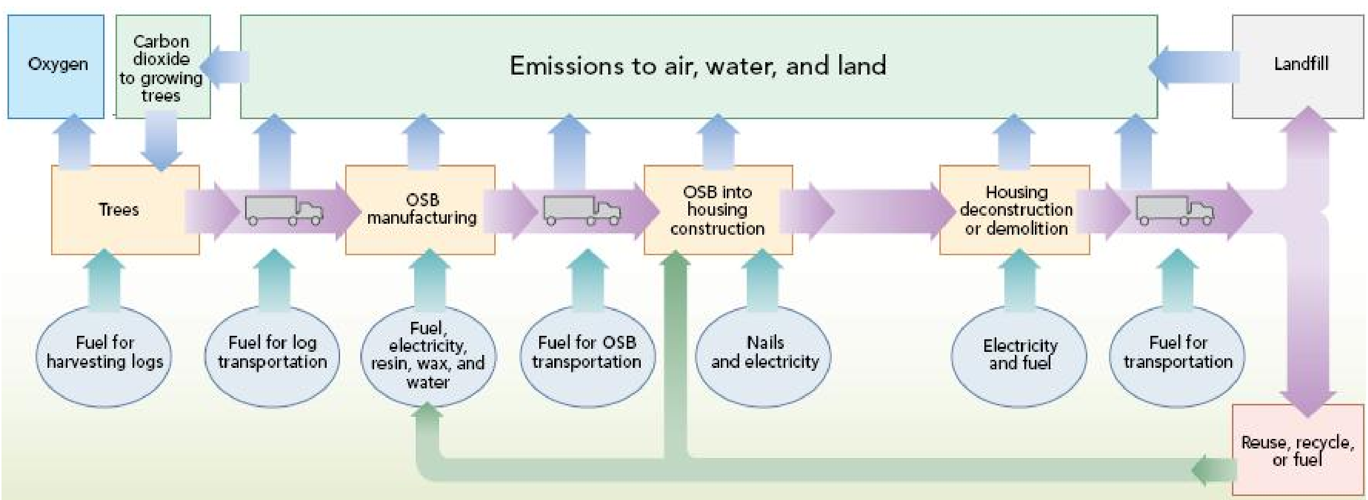

Figure 4: The typical life cycle of trees and the timber that is produced. Source: Gibson, 2007

One of the strongest solutions to building with timber is the use of Engineered Lumber. Engineered Lumber falls into five categories; Laminated Veneer Lumber (LVL), Manufactured Wood I-beams, Finger Jointed Lumber, Glulams and Manufactured Trusses. In general, using engineered wood is a more efficient way of using wood, as it utilizes small dimension lumber and reclaimed wood. Being able to compile structural members by using wood waste reduces the demand on our forests for full growth trees. Engineered lumber has been found to oftentimes outperform solid dimensional lumber with its resistance to shrinking and cracking. Its strength and precise measurements also offer a reliable consistency in construction (Sullivan & Horwitz-Bennett, 2009). Engineered Lumber is a great solution to using timber in construction as it not only reduces the demand on the environment, but when labor costs and reduced job site waste is accounted for; the cost is highly competitive with that of solid dimensional lumber. Currently, there is not a market for reclaimed timber in structural portions of buildings. This is due to the testing required to insure the structural integrity of the member was not lost in its first life cycle. Most of the reclaimed wood today goes into architectural finishes such as wood flooring or shingles (Sherman, 1998).

STRUCTURAL INSULATED PANELS:

When working with timber construction, there are many options for sustainable design that go further than just choosing between engineered wood or solid dimensional lumber. One such solution is the recently predominant use of Structural Insulted Panel Systems (SIPS). SIPS can be made out of many different materials, but they are generally panels insulated with foam core, and faced with Oriented Strand Board or Cement Particle Board (Siphouse). They are used in conjunction with timber framing to form walls, floors, or roofs with a continuous insulation that is not bridged by timber studs. Both faces of the panels are sheathed, which allows SIPS to resist much higher wind forces than conventional timber framing. The high strength and R values that these panels provide allow for a great reduction in the amount of timber material used. The University of Oregon built a house to demonstrate the use of Structural Insulated Panels and SIPTEC reported that they “saved 2,720 board feet of wood that’s nearly 50% of the framing timber for conventional construction and the house required 161 fewer man-hours to build” (Siphouse). Not only are SIPS strong structural members, but the efficiency of insulation can save up to 60% of energy use for a SIP building compared to one of equal size that is timber-framed. (Siphouse) The sustainable qualities, in terms of lumber reduction and energy, make this simple construction method a good solution. A SIP can be seen in Figure 5 during the manufacturing process.

Figure 5: The production of a compressed straw SIP. Source: Alter, 2008

It is important to note, that as with most new age sustainable solutions, there are new complications that arise from the use of Structural Insulated Panels (SIP). Phenol formaldehyde resin is often used as the binding material for the exterior OSB – and it is a chemical that can release gasses that are bad for indoor air quality. Also, SIPs are often insulated with polystyrene boards, which are an already prevalent problem because Styrofoam is a petroleum intensive material that is not biodegradable (ThinkDwell, 2008). Agriboard, a sustainable focused engineering firm out of Texas, has attempted to tackle these issues that come with a potentially 'green' building material. They have created a SIP that uses wheat and rice straw for the insulation, and a formaldehyde-free OSB. By heating and compressing the straw, its lignin acts as a natural binding material – and the CO_2 that would otherwise be released from the straw is trapped in the panel, making it essentially carbon negative (Alter, 2008). These SIPs are not exactly as strong as ones with Styrofoam, but they still come with the sustainable, efficient, and simple benefits of a Structural Insulated Panel.

STEEL:

Steel is another premier material used in today's construction field and it provides many unique qualities and uses for today's construction demands. A majority of the steel that is produced is for the use in building construction, as shown in Figure 6. Steel is very under-utilized by the residential sector today, but steel's pure strength and flexibility lends itself as a viable replacement to traditional lumber construction, and provides extended life span expectancies. Generally, it would require 40-50 full growth trees, about an acre of forest, for the construction of a 2000 square foot home. The same house could be constructed using steel, and would only require 6 scrapped automobiles (Recycle-Steel, 2008). Not only does this method require less material overall, but it introduces the use of recycled materials in place of natural resources. Aside from the amount of material used when applying steel construction in place of timber, the overall quality of material is more consistent, and the independence from water content and pest resistance is complimenting. The overall use of steel, in place of timber, can also reduce the demand on EQ, as well as cut down on transportation costs and emissions. Also, because the use of steel does not possess the same fluctuations of the lumber market, the overall cost of steel production is very stable in the long term. The steel industry recognizes all of the obvious paybacks that steel construction provides, and is working to shift the focus from volume of steel manufactured, to the production of light, safe, long lasting steel. They are also working with contractors to make products that are easy to recycle at the end of their life cycle (World Steel Association, 2008).

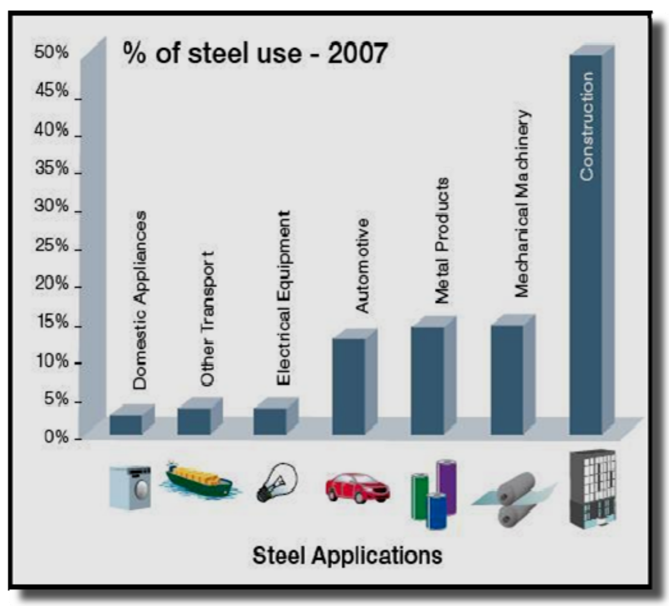

Figure 6: The percentage breakdown of steel usage in 2007. Source: WorldSteel Association, 2008

The focus on producing recyclable steel products is new, but steel has always lent itself well to the concept of a recycled life span. Almost 80% of the steel that comes from production sites has some form of recycled content, and is continually moved in the recycling loop life of steel. Because steel does not lose its strength when reheated and reshaped, it is available to be recycled and reused for an infinite amount of uses (Recycle-Steel, 2008). Even before the model of sustainable design became a predominant means of construction, the steel industry was recycling every piece of steel they could get their hands on. Steel mills recycle millions of tons of pre and post consumed steel, including appliances, automobiles, and construction material every year to produce new steel products. To date, more than 62% of the steel circulating through the domestic steel industry has been recycled. Not only does steel recycling reduce the cost of overall manufacturing of materials, but the steel industry alone saves enough energy to power 18 million households a year, simply by using as much recycled material as possible (Recycle-Steel, 2008). The amount of energy required to produce virgin steel is almost four times the amount of energy it takes to recycle and reuse steel (Kang & Kren, 2007). Despite recycling already being such a strong forefront in the steel industry, it is imperative that we still understand the grave impacts that using steel has on our environment, and with that we must continue to move forward with improving how we utilize steel's natural recyclable qualities. Figure 7 shows the details of where the steel we use today comes from and what its intended life is.

For every ton of steel that is produced, approximately 1.7 tons of CO_2 is emitted, which is 70% more than concrete produces. Though we should not neglect that this is such a large number, it is still important to recognize that because the life span of steel is so much longer than other products, its overall CO_2 emissions are relatively lower (World Steel Association, 2008). Steel is made by combining iron ore, coke and limestone in a blast furnace. Carbon dioxide is produced in the process of making coke, and in the stage that carbon is extracted from the iron. Not only is carbon released in the process of making steel, but large amounts of carbon dioxide are also produced simply by burning charcoal to run the blast furnace for production. Researchers are presently working on a replacement material for coke, but until then, not only will CO_2 emissions continue, but at our present rate of development it is expected to more than double by 2050 (World Steel Association, 2008). In spite of the extensive steel recycling that is presently available, the life span of structural steel is so long that there is very little available to recycle at hand. A typical steel building or bridge is generally constructed with 50 to 100 year life span expectancy, and so to maintain our rate of construction development, the mining of virgin iron ore to produce steel is increasing annually. With what little material that is available for recycling, it takes approximately 0.4 tons of recycled material and 1.6 tons of virgin materials to make only 1 ton of steel (World Steel Association, 2008). Providing our steel structures with extensive life spans is a primary goal; therefore we must work to create efficient means of recycling for what steel is available for use.

Currently, the traditional production of steel members for construction involves an Electric Arc Furnace (EAF) or a Blast Furnace (BF). The EAF method produces steel from recycled steel by melting it using electricity. The BF method is more common, dating back to the early steel making period; it reduces the iron ore to molten iron saturated with carbon. The iron ore is then mixed with carbon gases and coke to make it a liquid iron. The liquid iron is then blasted with hot air to increase productivity and it becomes steel. A new technology is on the brink of mainstream production called FINEX. FINEX is an iron-making process that eliminates the need for coke in the iron making process (WorldSteel Association, 2008). This major change drastically reduces the emissions that are associated with steel making. As an added bonus, using the FINEX technology reduces costs up to 85% compared to the traditional BF method, due to the less required energy.

One of the 'green' alternatives that are in use currently for steel is 'Smart Beams.' These beams are wide flange shaped beams that are cut in a pattern, then shifted and welded back together, such that the beam now has a series of holes along the web and is significantly deeper, as shown in Figure 9. These beams utilize the strongest component of the member, which is the flange in bending. The web carries very little load, and therefore the portion that is left open makes a minimal impact on the structural strength of the beam. Smart beams are a prime example of sustainability; they use the material to its greatest ability. The process increases the depth by 50%, which in general increases the strength and stiffness by 40%. As an additional benefit the beams are welded together with camber built in, which eliminates an offline cambering process (Milligan, 2001).

A growing trend in commercial and residential buildings is the use of cold-rolled steel. These are growing in popularity due to the recyclable nature of steel versus traditional timber.

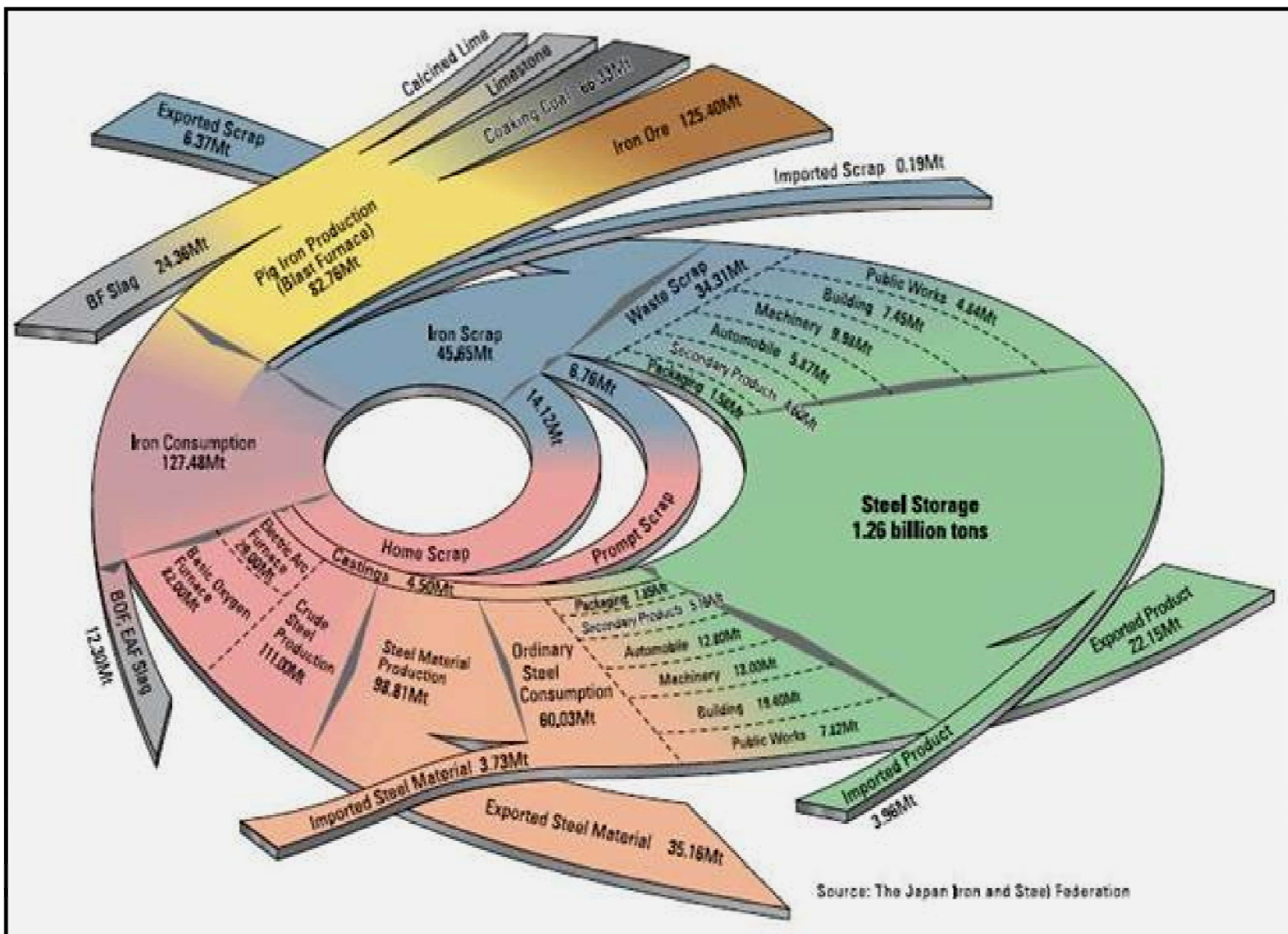

Figure 7: Iron and steel recycling loop in Japan. Source: WorldSteel Association, 2008

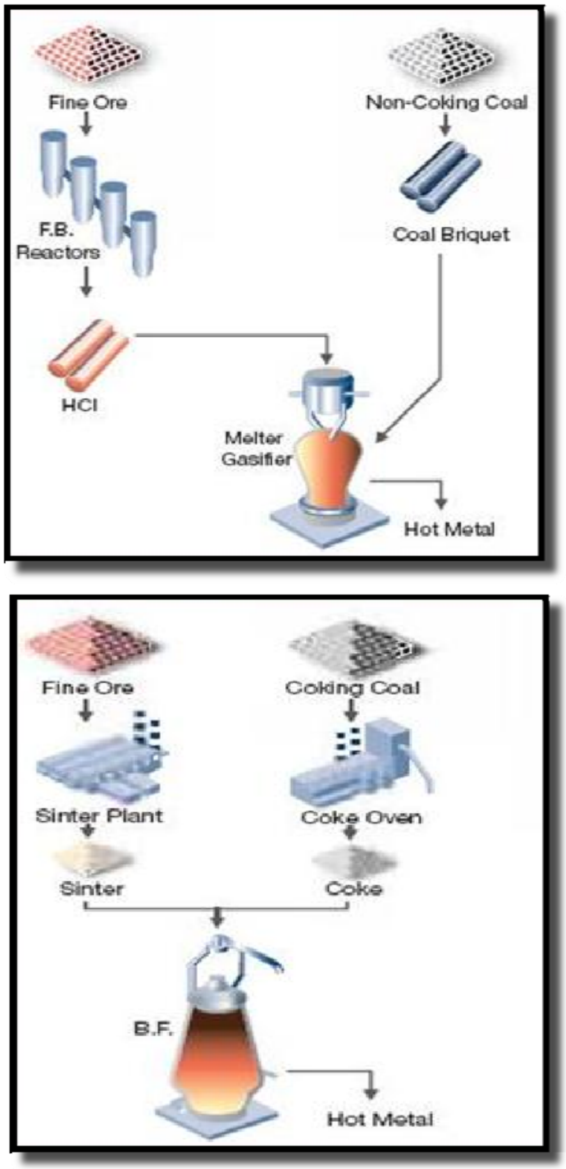

Figure 8: The steel making process, the traditional Blast method on top and the new method FINEX on the bottom. Source: World Steel Association, 2008

The cold rolled process is exactly that, rolling the gauge metal into channel shapes after the cooling process has been completed. Also, the added strength of steel helps to reduce the bill of materials for a project.

The current production of steel has shown that almost 100% of steel can be recycled and reused in some form. Therefore we must push the model of making the entire steel production process recycled. This can be done by confining and selling the produced CO_2 to local gas facilities. If done properly, this can essentially make steel production void of carbon dioxide emissions, as well as reducing the carbon that would have been required for the facility otherwise. Another more common practice, which was described earlier, is the use of slag from the steel plants, in the production of cement (World Steel Association, 2008). By using slag in cement, the CO_2 emissions that would have been released during concrete production can be reduced by 50%. The steel industry has gotten very close to their goal of having zero-waste of 100% efficiency; in 2006 they were at 97.2%. With the steel industry making such large strides towards sustainable solutions, they have been able to reduce their annual energy consumption by 60% in the last 25 years.

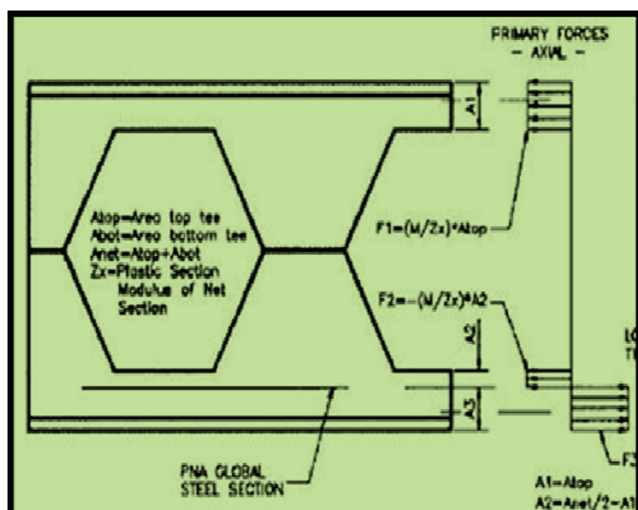

Figure 9: A Smart Beam configuration. This figure also depicts the loading path in the portions of the beam that where the web is not complete. Source: Milligan, 2001

These accomplishments have helped to push the industry to continue to develop new technologies to reduce energy consumption, reduce CO_2 emissions, and expand the use of recyclable steel that is already in production (World Steel Association, 2008). Also, by building energy reserving facilities, such as wind turbines – steel can help to efficiently create a negative carbon cycle.

The example of a wind turbine, if constructed efficiently with steel, could produce 80 times more energy than was used in its maintenance and production in only 20 years. Then, at the end of its life cycle, all of the steel can be recycled and used for future sustainable products (World Steel Association, 2008).

COMPARISON OF MATERIALS:

After analyzing the disadvantages and benefits of concrete, timber, and steel – it almost leaves us with a larger question, 'What do we do now?' Obviously, no material or process is perfect yet, but it all comes down to understanding each individual project and being educated enough in the concepts of sustainability to make the best decisions. Summarizing what we have found, we will walk through how to best utilize each material.

> "Green Building Purpose: to transform fundamental human assumptions that create waste and inefficiency into a new paradigm of responsible behavior that supports both present and future generations."
>
> – Charles J. Kibert

One of the most obvious things to keep in mind with concrete is the strength and quality. The demand for fast paced construction has diminished the overall structural integrity of concrete. By implementing proper curing times, and designing for appropriate strengths – the life span of concrete structures can be more accurate and hopefully improved. This also includes problems with overdesigning; many engineers will merely increase the reinforcing to a #5 rebar, when a #4 rebar is satisfactory. Not only does this overdesign go against the basis of sustainability, but it is often times not beneficial.

Using slag or fly ash is one of the best ways to improve the mixture of concrete. We saw the environmental benefits as well as the improved strength qualities these ingredients provide. Even the longer cure time that fly ash requires can be seen as a benefit, as it contributes to the overall strength of the concrete. It is also imperative to be selective in choosing which concrete plant to use; look for ones that emphasize water recycling and reuse, as well as minimal onsite debris. Focus on designing the formwork appropriately so that it can be used for multiple forms on the project, and potentially deconstructed for use on a future project. We did not concentrate on foundations in this report, but it is important that they are addressed with special considerations because they play such a vital role in any structure. Approach these sustainable solutions with caution – there is little to no research as to how applications, such as fly ash, work with concrete foundations underground.

When using timber, it basically comes down to using engineered lumber whenever possible. With so many modern applications readily available in the construction field, there is no reason to use solid sawn lumber in construction. We also saw the great benefits that designing with SIPs can provide. It is important to address using SIPs with caution though, as they are such a new application and need to be properly tested and approved by the engineer.

One of the best ways to design a timber structure is to focus on its ability to be deconstructed appropriately and efficiently in the future. If the building can be deconstructed, and is able to provide usable reclaimed timber for future construction, it can greatly benefit the entire life loop of the timber industry.

When using steel, try to design and implement new products and applications. The castellated Smart Beams provide great benefits in strength and sustainability, simply by using traditional structural members in a different way. When designing residential, use cold formed steel; the construction process is similar to that of traditional timber and it can be used for light applications and achieves higher load values than a typical timber member. When designing with steel, recycled material is not necessarily specified by the engineer – so it is important to be educated in the sustainable processes practiced by the plants. Seek FINEX products where applicable, and work with plants that are known for recycling their steel and CO_2. Again, it is important to not overdesign – it is not sustainable and provides no overall benefit.

GREEN BUILDING FINANCIALS:

When design teams begin to approach the concept of Green Building, they initially see it as a separate component all in itself. Peter Morris[4] believes that "This leads to the notion that green design is something that gets added to a project – therefore they must add cost" (Langdon, 2007). The general excuse for a firm not implementing green concepts into their projects is the perception that it will cost them large amounts of money. In some circumstances, this can be true; more innovative or high end solutions can be very expensive before they become regular in the construction industry. Peter Morris expresses that another reason why green design is perceived to be more expensive is because it is analyzed and presented incorrectly. He explains that, "The common fault is found when a team concludes a project and they say, 'the final project cost me this much; I originally thought it would cost that much; the difference must be what I spent on making it green'." The misconception here is that the original budget was correct in the first place, or that any possible change or addition was a completely green concept – neither of which is likely accurate. These are some common assumptions of additional cost that have been seen to get in the way of green design being fully accepted in the building sector.

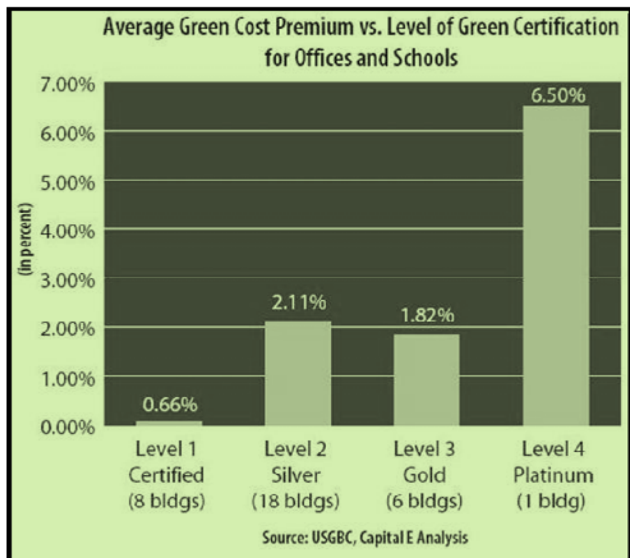

Figure 10: A bar chart that depicts the average up-front cost of certifing a leed building. Source: Kats, 2003

The truth is that sustainable design does not cost more; there is a large number of LEED certified building projects that managed to stay within their budget (Langdon, 2007). Langdon did a cost analysis on buildings that attempted to achieve LEED certification, and those that did not design with LEED in mind, and found that there was truly minimal cost difference. In truth, there is such a large variation in cost per square foot when comparing buildings in general that dividing them into whether or not they are 'green' has no real statistical significance. When drastic cost differences were found, it was due to differences in program types, and had nothing to do with whether the building designed with green in mind or not.

A downfall of the direct budget comparison method that is in use now is that it lacks the cost benefits of the long-term payback. In fact, a report by Gregory H. Kats[1] shows that "a minimal upfront investment of about 2% of construction costs typically yields life cycle savings over ten times the initial investment". A study was ordered by former Governor Davis in 2000, and at the time this report was the greatest effort in the financial analysis of green buildings. Because of the findings of the report, California made green/LEED buildings a priority for all new state construction. The first of which was the Education Headquarters Building, which saves taxpayers $500,000 per year in energy costs (Kats, 2003). Another benefit that is discussed in this study is the improvements in building comfort and control measures, and their influence on the productivity of the building's tenant. An improvement in the efficiency can have a long-lasting effect on the company's bottom line. Savings such as these are not listed in the current cost analysis methods, but must be included to get an overall picture of the long-term benefits of green buildings.

Another item that needs to be looked at is the cost of not having all of the design disciplines involved early in the building process. Team members need to be able to insure that their portion of the project works well with the others and doesn't cause any major last minute changes. It seems as though these last minute changes, which could potentially create a budget issue, could be reflected on to the cost of Green Building. Buildings can no longer be designed or built as isolated components; the exterior skin has impact on the interior space, and so on. This requires all of the design professionals to work closely together from start to finish (Morris, 2007). It is crucial to the final building output to have the design members work together for the goal of a green building.

Financial Benefits of Green Buildings
Summary of Findings (per ft²)

Category	20-year Net Present
Energy Savings	$5.80
Emissions Savings	$1.20
Water Savings	$0.50
Operations and Maintenance Savings	$8.50
Productivity and Health Benefits	$36.90 to $55.30
Subtotal	$52.90 to $71.30
Average Extra Cost of Building Green	(-3.00 to -$5.00)
Total 20-year Net Benefit	$50 to $65

Figure 11: A summary of the total Green Building costs over a 20-year study period. Source: Kats, 2003

Unfortunately, the cost of building green is what deters most clients from selecting green building as a goal for their project. This is a gross misconception, as discussed above, which needs to be corrected in order for the client to weigh all of the pros and cons of Green Building. The case study that was commissioned by the State of California is a start, but effort needs to be expanded nationwide. The cost of the building must be amortized to a cost per square foot for similar building categories. Last-minute budget breaking changes must be tracked and accounted for as well as the long-term benefits that are seen over the years after a building is completed. Until that is accomplished, a good short-term solution is to lean on design professionals for guidance. This is a very plausible option due to the growing number of LEED professionals in the architectural and engineering design positions.

MOVING FORWARD:

Woon/Energie, or W/E, consultants have compiled three main steps when it comes to choosing sustainable materials. The first is the prevention of unnecessary use and efficient use of materials. If detailed steps are taken at the beginning of the design phase, it is easy to minimize resources by optimizing the floor plan while focusing on future use of the building. Also, correctly understanding the life cycle of each component and system will allow for a maximized and accurate building life cycle. The second step is the use of renewable and recycled resources. When utilizing renewable materials, it is important to prepare the building for easy deconstruction at the end of its life cycle; the key is to design for deconstruction not demolition. Obviously, using recycled products in any project is a great step toward sustainable design. Though recycled resources are not in abundance now, with the participation in using renewable resources properly, we can assure that there will be beneficial materials for future generations to utilize. The third step is the selection of materials with the least environmental impact. Though this step is obvious, it is also the most complex in working through and the most difficult to accomplish. The only means of accomplishing this last step is having a basic understanding of each material or processes' environmental impact, not only present, but future as well, and being able to accurately balance the pros and cons based on each project individually (Anink et al., 2004).

Along with choosing the correct materials – maintaining a broad adaptive capacity is also important. When focusing on generality, flexibility, and elasticity for technical systems and planning aspects, the overall life span of the building is increased with its ability to adjust to future circumstances (Berge, 2009). Generally, it is the consideration that a space can be used for multiple purposes. This is beneficial for office spaces or warehouses that may have multiple companies and activities moving through it. Flexibility is incorporating floor plans or technical systems that can be changed or removed in the future. This is a very important aspect, seeing as we live in such a fast-paced society that is continually growing and changing. Preparing a building to adapt to new technology or infrastructures is one of the best ways to allow it to maintain a long life cycle into future generations. The idea of elasticity is designing the building to permit future expansion or contraction. This concept is much more difficult to attain, but one that offers great benefits for a sustainable building. This model not only allows the building to be connected to another building in the future, or even expanded on itself – but also focuses on the building being easily disassembled for multi use in the future. It is pointless to construct with materials that can be recycled after the building's life cycle is over, if the building cannot be easily deconstructed. By utilizing these basic concepts the life cycle of the building can be increased by up to 25% (Berge, 2009).

CASE STUDY:

In order to further understand the relationship between LEED and structural system material sustainability, a case study was done on a LEED Platinum building in El Centro, California. This building, the Windrush Elementary School, is a two story school wing that houses seven classrooms and a library, and the building is composed of concrete. A few of the green features of the building are solar panels, blue-jean insulation, low-flow faucets and toilets, as well as a natural lighting design that reduces the need for electrical lighting (WIDN, 2009).

The Windrush building is built from concrete with slag from the steel manufacturing process, as well as fly ash. Per the school, a total of 50-60% of the Portland cement was replaced with either slag or fly ash (WIDN, 2009). These are all great sustainable solutions that are compliant with LEED certification, but what about the sustainable qualities of the structural system? Pursuant to analyze the building from a material sustainability perspective, a copy of the gravity roof calculations was obtained to compare the carbon dioxide output of the specified concrete member to an equivalent steel beam. Roof Beam 1 (RB1) was analyzed, which has a span of 9'0" with a roof live load of 20 pounds per square foot and a dead load of 111 pounds per square foot. The original calculations call for a 12" x 14" beam with (2) #8 rebar along the bottom. A steel member that more than adequately carries the specified loading (the concrete dead loads were not reduced in order to account for the lighter steel member) is a W14x48, A992 steel. In order to compare the steel member to the concrete beam by the same standard, they must be converted into carbon dioxide outputs. These numbers only account for the carbon dioxide of the manufacturing process, not the added CO_2 of transport, installation, or connections. On average, one pound of concrete produces one pound of CO_2, and with the use of 50% fly ash or slag, that reduced the CO_2 output to 0.5 pounds per pound of concrete produced. (Reference the document from David Carmona). For steel, one pound of steel produces 1.7 pound of CO_2 (World Steel Association, 2008), albeit, this is a larger rate than concrete, steel more efficiently uses the material and a lighter member is created. Based on the members previously described, the concrete member has a CO_2 output of 825 pounds, and the steel member has an output of 330 pounds. The price for using concrete is a 250% increase in the CO_2 output. From these calculations, it can be shown that the concrete is the more detrimental material, yet the Windrush building was awarded the highest LEED certification.

CONCLUSION:

Earlier, we defined Building Sustainability as a broad design philosophy in which focus is driven towards minimizing the overall impact of the built environment on the natural environment and human health. By efficiently using water, energy, and natural resources, the environmental impact of a building can be minimized. As stated though, this definition is broad, and how a designer addresses these design issues is also very broad. What needs to be realized by the designer is that with every sustainable solution that is applied, a different environmental impact is generally neglected. The Windrush Elementary school case study is a pivotal example of this, in which the highest LEED designations were implemented, but the environmental impact of the structural system was neglected. Though this building was credited with LEED Platinum, can one really say that the building is sustainable? At the end of the day, the Windrush building footprint could have been smaller, the life span extended further, and the amount of materials used minimized. This isn't to say that the project was a failure in sustainable design, only that the Green Building philosophy should entail more than simply checking off a list of credits.

The key to sustainable design is simply being educated. By having a strong understanding of the anticipated use of the building, as well as the future life cycle of the building, the designer will be able to apply their knowledge of sustainable materials to the best design solutions applicable. As an engineer, it is imperative that the design of the structural system is not neglected until the final design phases of the building are completed. As presented earlier, a cohesive, integrated approach will allow for the strongest design solutions to surface in the beginning phases of the project. This will allow for the engineer to make the best decisions, based on their education of materials, for the core structure of the building. Thus, allowing for an interconnected, sustainable design. No application will be perfect, and in most cases there will be no check list to run through – but by understanding the environmental implications and the coinciding solutions, the most sustainable building possible can be constructed.

> "The natural **recyclability** of steel makes it a beneficial building material, and lends itself to acquiring more readily **sustainable** applications in the future of construction."

When given the choice of which material to use, break free of industry routine and use steel for as many different applications as possible. Steel is a material that lends itself well to a multitude of shapes, sizes and applications. By replacing traditional timber construction and concrete construction with steel, the entire life span of the building can be drastically extended – with little to no additional cost acquired. The natural recyclability of steel makes it a beneficial building material, and lends itself to acquiring more readily sustainable applications in the future of construction.

In addition to understanding the sustainable implications of the materials, the factor of cost must not be overlooked. Despite the initial conception that building green adds cost to the overall project, detailed research has shown that this is not the case with accessible solutions. When sustainable applications are properly addressed in a building, it not only provides a competitive cost but it also saves operational costs over the lifespan of the building. This provides a return on the original building cost that would not have been seen with traditional construction processes. Sustainability not only helps save the environment, but it also saves the client a large amount of money.

Green Building is a design philosophy that is sweeping this nation, and impacting many design solutions. For this concept to have the greatest positive impact on our environment now, and in the future, it must not be left to just the Architects. The structural system of a building is the core of a project – and the implications that come with the design of that core can often times be more detrimental than anything else. If the structure is properly designed with an extended life cycle in mind, along with low environmental impacting applications – then our industry will in fact be meeting present needs without compromising the ability of future generations to meet their own needs.

APPENDIX:

1. **Gregory H. Kats** is the founding Principal of Capital E, a national clean technology deployment and strategy firm. He is the chair of the Energy and Atmosphere Technical Advisory Group for LEED and serves on the LEED steering Committee.
2. **P. Kumar Mehta** is Past Chair of the ACI Commemorative Lectures Series Committee and is a member of the ACI Board Advisory Committee on Sustainable Development and ACI Committee 232, Fly Ash and Natural Pozzolans in Concrete. He holds nine patents in the area of cement and concrete technology, and is the author or coauthor of nearly 250 scientific papers and four books
3. **Bradford Russell** holds professional licenses as an architect and a structural engineer and was one of the first LEED Accredited Professionals in the US and Texas. Mr. Russell is currently working towards a PhD from Southern Methodist University in the subject matter of incorporating 'green' design / materials into the practice of structural engineering.
4. **Peter Morris** is a Principal with Davis Langdon and head of the firm's research initiative, and was selected in 2009 as Chair of the US Green Building Council's Research Committee. He has 25 years of experience in facilities evaluation, construction cost planning and management, including 24 years in California with Davis Langdon.
5. **Charles J. Kibert** was vice-chair of the Curriculum and Accreditation Committee of the U.S. Green Building Council (USGBC) and helped create the first ever student chapter of the USGBC for which he serves as faculty advisor.He is a Professor and Director of the Powell Center for Construction and Environment at the University of Florida

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Windrush School Roof Beam #1:

Span = 9'-0"
Live load = 20 psf
Dead load = 111 psf
Tributary width = 28.75'
All data is from windrush calc package provided by the City of El Cerrito, CA

Analysis of Alternative Options:

Timber:

Governing load case: D+L
$W_{total} = (20 + 111)\,psf \cdot 28.75' = 3770\,\#/ft$

Per Forte calc 5.8 calculations, use a 5¼" x 14" 2.0E Parallam for RB1.

Deflection = 0.232" < $\frac{\ell}{360}$
0.232" < 0.30" okay ✓

Steel:

Load Cases:
$1.4D = 1.4 \cdot 111psf \cdot 28.75' = 4470\,\#/ft$
$1.2D + 1.6L = (1.2 \cdot 111psf + 1.6 \cdot 20psf) \cdot 28.75' = 4750\,\#/ft$ ← governs

Try W14 x 48. A992 steel:
Bending:
$M_u = \frac{wL^2}{8} = \frac{4750\#/ft \cdot 9^2 ft^2}{8} = 48.1\,kft$
$M_n = F_y \cdot Z_x = 50ksi \cdot 78.4in^3 \frac{1\,ft}{12\,in} = 326.7\,kft$
$\phi M_n = 0.90 \cdot 326.7kft = 294\,kft > 48.1\,kft$ okay ✓

Shear.
$V_u = \frac{wL}{2} = \frac{4750\#/ft \cdot 9\,ft}{2} = 21.375k$
$V_n = 0.6 F_y \cdot A_w \cdot C_v$
Determination of C_v:
$h/t_w = 33.6$
$1.10\sqrt{\frac{k_v E}{F_y}} = 1.10\sqrt{\frac{5 \cdot 29{,}000}{50}} = 59.23$
$h/t_w < 59.23 \therefore C_v = 1.0$
$V_n = 0.6 \cdot 50ksi \cdot 13.8" \cdot 0.340" \cdot 1.0 = 140.76\,k$
$\phi V_n = 0.90 \cdot 140.76k = 126.7k > 21.375k$ okay ✓

Deflection:

$$\Delta = \frac{5wL^4}{384EI} = \frac{5 \cdot 4760\#/ft \cdot 9^4 ft^4}{384 \cdot 29000000\frac{\#}{in^2} \cdot 484 in^4} \cdot \frac{12^3 in^3}{1 ft^3}$$

$\Delta = 0.05''$

$\Delta_{max} = \frac{L}{360} = \frac{9 \times 12}{360} = 0.30'' > 0.05''$ okay ✓

Use W14X48, A992 for RB1

Energy output Comparison:

Weight of Concrete beam $= 150\frac{\#}{ft^3} \cdot 12in \cdot 14in \cdot 9ft \frac{1\ ft^2}{12^2 in^2} = 1575\#$

Weight of rebar: $2bars \cdot 0.79 in^2 \cdot 9ft \cdot 490\frac{\#}{ft^3} \frac{1\ ft^2}{12^2 in^2} = 50\#$

Rate of CO_2 Emissions for concrete w/ slag/flyash

For every pound of concrete, 1 pound of CO_2 is produced

Per Windrush 50% slag/flyash was used. Reduce to 0.50:1 Ratio

Rate of steel Emissions for steel:

For every ton of steel, 1.7 tones of CO_2 is produced [World-steel '05]

Although, using recycled steel it reduces that CO_2 production by 55%. [World steel, Advanced Steel applications]

CO_2 produced for specified RB1 $= 1575\#conc \frac{1\#\ of\ CO_2}{1\#\ of\ conc} \times 0.50 + 50\#steel \frac{1.7\#\ CO_2}{1\#\ steel} \cdot 0.45$

Total concrete CO_2 output $= 825\#\ CO_2$

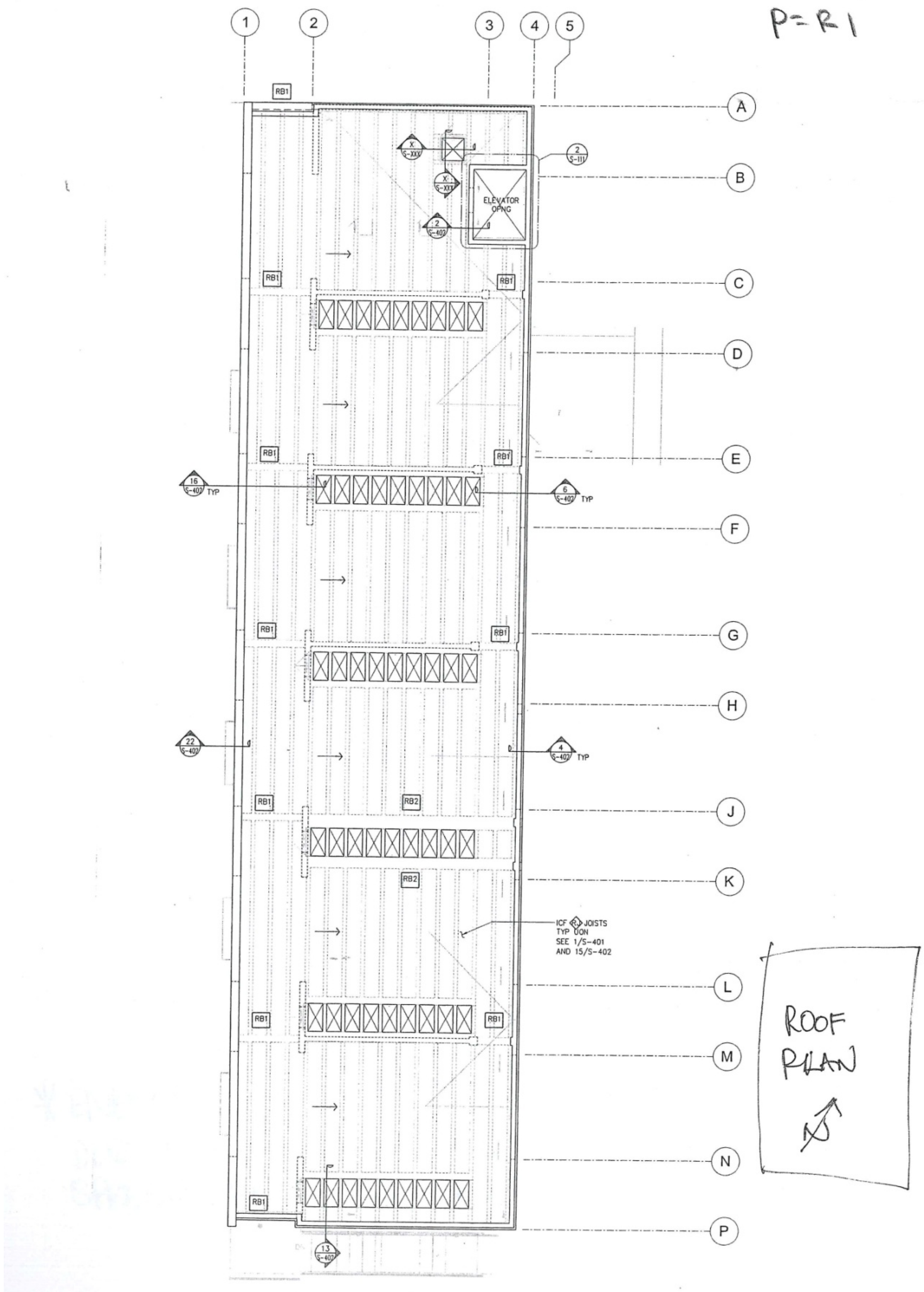
Weight of Steel Beam option: $14.1 in^2 \cdot 9ft \cdot 490\frac{\#}{ft^3} \frac{1\ ft^2}{12^2 in^2} = 431.8\#$

CO_2 produced by W14X48 $= 431.8\#steel \cdot \frac{3400\#\ CO_2}{2000\#\ steel}\ 0.45$

Total CO_2 for W14X48 $= 330\#\ CO_2$

DESIGN GRAVITY ROOF BEAMS

P=R1

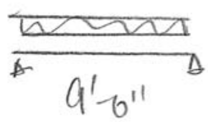


INGRAHAM·DEJESSE ASSOCIATES
Consulting Structural Engineers

date: 5/07 page: R2
by: SJF job # 06032
project: WINDRUSH

DESIGN
ROOF BEAMS

RB 1



trib = 28.75'

w_{D} = 111 psf (trib) = 3191 #/'

w_{L} = 20psf (trib) = 575 #/'

w_{SELF} = 12" x 14" x 145 = 169 #/'

USE 12" x 14" beam w/ 2#8 T & B

V_u = 25.57 kips

V_c = 15. kips

USE #4 @ 6" OC

* ENERCALC DOES NOT CALCULATE DISPLACEMENT DUE TO LONG TERM (CREEP + SHRINKAGE). A SPREEDSHEET WAS CREATED TO CHECK DISPLACEMENT

Ingraham DeJesse Associates Inc.
1629 Telegraph Avenue, Suite 300
Oakland, CA 94612
tel (510) 834-1629
PAGE: R3

Title : Windrush
Dsgnr: JYF
Description :

Scope :

Job # 06032.4
Date: 1:42PM, 2 MAY 07

Rev: 580000
User: KW-0601846, Ver 5.8.0, 1-Dec-2003
(c)1983-2003 ENERCALC Engineering Software

Multi-Span Concrete Beam

gravity.ecw:Calculations

Description RB1

General Information

Code Ref: ACI 318-02, 1997 UBC, 2003 IBC, 2003 NFPA 5000

Fy	60,000.0 psi	All Spans Considered as Individual Beams		ACI Dead Load Factor	1.40
f'c	3,000.0 psi	Stirrup Fy	60,000.0 psi	ACI Live Load Factor	1.70

Concrete Member Information

Description			RB1
Span		ft	9.00
Beam Width		in	12.00
Beam Depth		in	14.00
End Fixity			Pin-Pin
Reinforcing	Center	Area	1.58in2
		Bar Depth	11.50in
	Left	Area	
		Bar Depth	
	Right	Area	
		Bar Depth	

Loads

Using Live Load This Span ??		Yes
Dead Load	k/ft	3.360
Live Load	k/ft	0.575

Results

Beam OK

Mmax @ Cntr	k-ft	57.53
@ X =	ft	4.50
Mn * Phi	k-ft	70.72
Max @ Left End	k-ft	0.00
Mn * Phi	k-ft	0.00
Max @ Right End	k-ft	0.00
Mn * Phi	k-ft	0.00
		Bending OK
Shear @ Left	k	25.57
Shear @ Right	k	25.57

Reactions & Deflections

DL @ Left	k	15.12
LL @ Left	k	2.59
Total @ Left	k	17.71
DL @ Right	k	15.12
LL @ Right	k	2.59
Total @ Right	k	17.71
Max. Deflection	in	-0.163
@ X =	ft	4.50
Inertia : Effective	in4	1,142.07

Shear Stirrups

Stirrup Rebar Area	in2	0.400
Spacing @ Left	in	6.00
Spacing @ .2*L	in	6.00
Spacing @ .4*L	in	Not Req'd
Spacing @ .6*L	in	Not Req'd
Spacing @ .8*L	in	6.00
Spacing @ Right	in	6.00

INGRAHAM·DEJESSE ASSOCIATES
Consulting Structural Engineers

Subject: Pan Joist Design	Job Number: 06032	Date: 05/02/07
Job: Windrush School	Engr: JYF	Page: R5

Design Roof Beam at Floor: RB1

Input Data

Section:

b =	12 in	
h =	14 in	
d =	11.5 in	
d' =	2 in	

Material Properties:

f'c =	3,000 psi	
fy	60,000 psi	
Es =	29,000 ksi	
Ec =	3,156 ksi	
n =	9.19	

Reinforcement Info:

As =	2 # 8	
	= 1.57	in^2
rho =	0.0114	
As'=	2 # 8	
	= 1.57	in^2
rho' =	0.0114	
Span =	9.0 ft	

Allowable Deflections:

$\Delta_{i,LL,\ allowable}$ =	0.60 in	=L/180
$\Delta_{total,\ allowable}$ =	0.45 in	=L/240

Demands (Simply Supported Beam):

Tributary Width =	28.8 ft
w_{DL} =	3,191 lb/ft
$w_{self\ weight}$ =	169 lb/ft
w_{LL} =	575 lb/ft
M_{DL} =	34.0 k-ft
M_{LL} =	5.8 k-ft
M_{Sus} =	36.9 k-ft
Deflection Factor =	5/48

Calculations:

Ig =	2,744 in^4
B =	0.83
r =	0.89
kd =	3.82
Icr =	1,117 in^4
fr =	411 psi
y_t =	7 in
Mcr =	13.42 k-ft

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INGRAHAM·DEJESSE ASSOCIATES
Consulting Structural Engineers

Subject:	Pan Joist Design	Job Number: 06032	Date: 05/02/07
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Flexural Capacity:

ϕ =	0.90	
a =	3.08 in	
ϕM_n =	70.40 k-ft	
M_u =	57.53 k-ft	
DCR =	0.817	ok

Deflection due to Initial Dead Load

$Ie_{i,DL}$ =	1,217 in^4	
$\Delta_{i,DL}$ =	0.129 in	

Deflection due to Sustained Load (DL+0.5*LL)

Ie_{sus} =	1,195 in^4	
Δ_{sus} =	0.140 in	

Deflection due to DL+LL

$Ie_{i,DL+LL}$ =	1,179 in^4	
$\Delta_{i,DL+LL}$ =	0.151 in	
$\Delta_{i,LL}$ =	0.022 in	ok, < L/180

Deflection due to Creep and Shrinkage

lamda =	1.275	
Δ_{cp+sh} =	0.179 in	

Total Deflection

$\Delta_{cp+sh} + \Delta_{i,LL}$ =	0.201 in	ok, < L/240

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