AN ABSTRACT OF THE THESIS OF

Hana D'Acci for the degree of Honors Baccalaureate of Science in Civil Engineering presented on May 31, 2012. Title: Sustainable Design Programs in the United States and Chile.

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The purpose of this thesis is to examine and compare sustainable design methods used in the United States and Chile, focusing on sustainable materials and certification programs, to see if sustainable design methods used in the United States can be implemented in Chile to further its sustainable development. Through literature review, it was determined that while Chile uses the United States-based Leadership in Energy and Design certification program, people are much less familiar with it than in the United States, decreasing its effectiveness in Chile. Chile also has available sustainable materials that are not extensively used. Chile's sustainable development would benefit from increased use of sustainable materials, like recycled concrete aggregate and wood, and through the use of a more stringent certification program like the Living Building Challenge to provide examples of highly sustainable projects. In both the United States and Chile, promoting and educating society in the need for and feasibility of implementing sustainable design is necessary to further sustainable development.

Key Words: sustainable, building, materials, LEED

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Sustainable Design Programs in the United States and Chile

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

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INTRODUCTION

The sustainable building marketplace is growing rapidly. With this growth, many definitions have been developed for sustainability, often based on what a group's goals are in becoming more sustainable. The United States Green Building Council, USBGC, works to achieve sustainability through cost-efficient and energy-saving buildings (USGBC 2011). The International Living Future Institute defines true sustainability as "socially just, culturally rich, and ecologically benign," and defines a sustainable building as "a building informed by its bioregion's characteristics, that generates all of its own energy with renewable resources, captures and treats all of its water, and operates efficiently and for maximum beauty" (ILBI 2010). An ideal truly sustainable project would either conserve or restore the environment by achieving net zero energy demand, water use, and greenhouse gas emissions. It would also use limited or no finite natural resources. Additionally, it would provide a healthy environment for those using it.

Sustainable design is a growing industry throughout the world. Certification programs are providing means and incentive for people to design projects sustainably. The United States has made advances in sustainability through ongoing research across the country and sustainable design certification programs like the USGBC's Leadership in Energy and Environmental Design, LEED, certification program. Many countries, like Chile, have established a national Green Building Council and are working towards sustainable development, but are not as advanced as the United States. This thesis will cover sustainable development happening in the Unites States and Chile, specifically what certification programs are used and what sustainable materials are available and used. These will be compared to see if there are areas in Chile's sustainability that can be improved by applying methods already used in the United States.

BACKGROUND INFORMATION

With the mounting negative impacts from air and water pollution, climate change, and the dwindling supply of finite natural resources for energy use, people have become much more aware of the need to correct these issues in order to keep the world habitable for future generations (ILBI 2010). The construction, operation, and deconstruction of buildings play a significant role in energy consumption, waste production, and pollution. In the United States, buildings account for 40 percent of primary energy use and 39 percent of CO_2 emissions (USGBC 2011). Sustainable design has become an important part of new building construction and renovation in order to preserve and restore the environment. Materials used in sustainable design are chosen because of their sustainability in relation to their obtainment, processing, transportation, construction, and to the building operation. They need to be extracted and processed in a way that produces minimal waste and air and water pollution. If possible, they should be obtained from a local source in order to decrease natural resource use and the air pollution from transportation. They also cannot contain products that would be extremely harmful to the environment if the building were partially or fully deconstructed.

The process of reaching sustainable design for most or all future building projects faces multiple challenges. One of the biggest is the higher initial cost. Some materials, like sustainably harvested wood, will be higher cost because of the more careful, environmentally conscious way they have been obtained and manufactured (de Bonafos 2001). They may also have a higher cost because they are limited to what additives can be in them (ILBI 2010). This may make getting a material to the necessary strength much more expensive. Also, when thermal mass is used for energy efficiency, much more material is needed, raising the overall cost of the building. Many new sustainable technologies are still being developed and optimized, so their cost can be high (Kats 2003). Customers need to look past the initial costs and realize the environmental and long-term economical benefits of making sustainable design choices.

Another challenge is the limited availability of sustainable materials. In sustainable design, the use of many conventional, commonly used building materials is highly discouraged because of the harmful chemicals they contain and their negative impact on the environment during manufacturing and service (ILBI 2010). Alternatives to many of these materials that are as easily attainable and similar in structural properties are not always available, or can be more expensive than the conventional materials (Ackerman 2002). The analysis of these new materials in the building design can be very different, creating more work for the designer, causing a higher cost for the customer.

As sustainable design methods are still being developed, another challenge is the funding for development of new technologies and systems. Ample research and experimentation must be done to come up with new methods of sustainability. These methods also need to be constantly reworked to make them more feasible and cost effective for real world applications.

Another challenge is to educate society on the need for increasingly sustainable buildings. Many people do not like change, especially if they have been doing things one way successfully for years, and are now told that they need to completely change their ways.

In the United States, many programs and incentives have been put into place to encourage building owners and designers to include sustainable aspects in their building projects. One of these programs is the LEED certification program. LEED is working to promote some level of sustainability in as many new building projects as possible through cost-efficient and energy-saving methods. It has a rating system where a building is given a sustainability score in multiple areas, and is given a LEED ranking based on the final score. Since it began, thousands of building projects of all types and sizes have become LEED certified (LEED Project Directory 2011). The LEED certification program is also extending its influence internationally to help promote sustainable building around the world. Another program is the Living Building Challenge. This program has seven areas of sustainability with strict requirements that each project must meet. Unlike others, this program bases a building's sustainability on its actual performance instead of its expected performance.

SUSTAINABLE DESIGN PROGRAMS

One of the best ways to promote sustainable design is to use certification programs. These types of programs provide a standard to measure the sustainability of a building project. They also assist designers in examining several areas in which a building can be made more sustainable, as well as providing possible methods to do so.

Sustainable Design Programs in the United States

LEED Certification

One of the most common and well-known sustainable building programs is LEED, or Leadership in Energy and Environmental Design. This certification program, established by the U.S. Green Building Council in 2000, provides a standard for various sustainable elements of a project and evaluates the environmental performance of the whole building. The LEED system can be used for a variety of projects including new construction, renovations, restorations, and operation and maintenance. Each of these areas has a slightly different rating system. The new construction and major renovation system has seven categories that are judged for sustainability, five of which are environmental categories. These are sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, and regional priority. In each category, there are required prerequisites that every project must meet to be considered for LEED certification. These minimum building requirements are meant to give clear guidance to customers, protect the integrity of the LEED program, and to reduce challenges that occur during the certification process (LEED 2011). Beyond the prerequisites, each category is then broken into credits, each containing a certain number of points that can be earned, giving a total possible score of 100 base points with 10 possible bonus points for innovation in design and regional priority. Multiple credits have alternative ways of obtaining points, including alternative methods for international projects. Based on the points a project earns, and given a proper credentialing process, it will receive a certification of certified, silver, gold, or platinum. This thesis will focus on the credits that can be earned for sustainable materials and resources.

Materials And Resources

The materials and resources section has a total possible 14 points split into 7 credits. The prerequisite for this section is storage and collection of recyclables in order to reduce the amount of waste generated and put into landfills. Easily accessible areas must be provided throughout the entire building for recycling at minimum paper, corrugated cardboard, glass, plastic, and metal.

The first credit in materials and resources is in building reuse. This is intended to extend the life cycle of existing buildings, conserve resources, reduce waste, and reduce negative environmental impacts of the manufacture and transport of materials for new construction. One to three points are awarded for reuse of 55 to 95 percent of existing structural floor, roof decking, and framing. Any hazardous materials that have to be removed are not included in this percentage. Another point can be earned for the reuse of interior nonstructural elements, like interior walls, doors and floor coverings, in at least 50 percent of the completed building.

The second credit is construction waste management to reduce the amount of debris from demolition and construction that gets disposed in landfills. A construction waste management plan must be created that identifies materials that will be diverted from disposal, excluding excavated soil and land-clearing debris. One to two points are awarded for 50 to 75 percent of debris recycled or salvaged.

The third credit is for the reuse of building materials to reduce the use of natural resources and reduce waste. The cost value of the salvaged, refurbished, or reused materials must constitute at least 5 to 10 percent of the total value of materials for the project. This only includes permanent building materials and not any mechanical or electrical components.

The fourth credit is to incorporate recycled content materials into the building to reduce negative impacts from extracting virgin materials. The sum of postconsumer recycled content plus half of the preconsumer content must be at least 10 to 20 percent of the material by weight in order to earn 1 or 2 points for this credit. As in the third credit, mechanical and electrical components are not included.

Credit 5 gives 1 to 2 points for the use of regional materials to support the use of indigenous resources and to reduce negative impacts from transportation. A minimum of 10 to 20 percent of a project's materials based on cost must be extracted, harvested, or recovered, and manufactured within 500 miles of the project site. Mechanical and electrical components are not included. For projects outside the U.S., the distance from the project can be determined by a weighted average from the types of transportation used. Rail transportation is divided by a factor of 3, inland waterway transportation is divided by 2, transportation by sea is divided by 15, and any other form of transportation is taken as is.

The sixth credit awards 1 point for the use of rapidly renewable materials in order to reduce the use and depletion of finite raw materials. For this credit, 2.5 percent of the total value of all building materials and products must be rapidly renewable materials. These include products made from agricultural products harvested within a 10-year or shorter cycle.

The seventh credit is for certified wood, which is intended to encourage environmentally responsible forest management. To earn the 1 point for this credit, a minimum of 50 percent of wood-based permanent materials and products used in the project must be certified with the Forest Stewardship Council (LEED 2011).

Living Building Challenge

Launched in 2006 by the International Living Building Institute, the Living Building Challenge is a program to promote the highest level of sustainable design for projects of all types and sizes. It provides a framework for the design, construction, and use of sustainable buildings. Instead of just looking at sustainable design and construction of the building, it goes further by achieving a sustainable relationship with its users and communities, creating and promoting a sustainable lifestyle. The goal of LBC is to “envision a future that is socially just, culturally rich and ecologically benign” (ILBI 2010). The ideal goal is to have “every single act of design and construction make the world a better place” (ILBI 2010).

Unlike other sustainable certification programs, the Living Building Challenge is based on actual building performance instead of just the design and expected performance of a building. The goals go beyond just reducing negative impact to the environment to also include sustainability criteria categories, or petals, for culture, beauty, biodiversity, and a deeper understanding of the benefits of and need for sustainable building.

The International Living Building Institute purports this type of sustainable building is necessary to save nature and allow for the future survival of the human race. With finite natural resources being depleted, biodiversity constantly in decline, increasing pollution and global warming, ILBI sees incremental steps of changing to sustainable building practices as not enough (ILBI 2010).

The LBC is divided into seven categories, comprised of 20 imperatives, depending on the project type, that must be met for each building project (ILBI 2010). Depending on certain factors including the location, building use, and available materials and labor, the strategies will change but the overall imperatives will remain the same. The seven categories are site selection, energy, water, health, materials, equity, and beauty. In this thesis, materials will be the main focus.

Materials

The purpose of sustainable material selection for the Living Building Challenge is to limit resource depletion, energy demand, pollution, waste put in landfills, and adverse health effects. The carbon footprint of the building is taken into account for the entire life cycle of the materials including harvesting, processing, transporting, construction, use, deconstruction, and reuse or recycling. Going beyond just the direct sustainability of the material, it also has to come from companies with sustainable practices and fair labor practices. If materials must be ordered from an industry without sustainable practices, the project team must send a letter to the corresponding national trade association encouraging the development and enforcement of sustainable practices. The purchase of the materials should also support regional economy.

A material conservation plan must also be created. This is aimed to reduce or eliminate product waste throughout the material life cycle. Depending on the material type, 80 percent to 100 percent of material waste must be diverted from landfill. To help achieve reach this threshold, adequate recycling and composting facilities are required on the building site.

All building materials must come from the region. This is meant to cut down on transportation pollution, as well as support the growth of a regional economy with sustainable practices. The maximum distance from which materials can be shipped depends on the material. Table 1 below shows maximum distances for different building materials and technologies.

Table 1: Maximum distances for obtaining building materials (ILBI 2010).

Zone	Max. Distance	Materials or Services	MasterFormat 2004 Classification
7	20,004 km	Ideas	-
6	15,000 km	Renewable Technologies	Divisions: 42, 48
5	5,000 km	Assemblies that actively contribute to building performance and adaptable reuse once installed	Divisions: 08 (all exterior products), 11*, 14*, 22, 23*, 26*, 33*, 44* Sections: 07 33 0057, 07 50 00*, 10 21 23*, 10 22 00*, 10 70 00*, 44 40 00*
4	2,500 km	Consultant Travel	-
3	2,000 km	Light or low-density materials	Sections: 07 31 00, 07 40 00, 09 50 00, 09 60 00
2	1,000 km	Medium weight and density materials	Divisions: 0660, 08 (all interior products) Sections: 07 32 00, 09 20 00, 09 30 00, 12 30 00
1	500 km	Heavy or high-density materials	Divisions: 03, 04, 05*, 31, 32

* Zone designation refers to the location of the manufacturing facility only; raw material sourcing is not tracked.

Some materials, like the majority of those in Zones 2 and 3, are limited on their distance from the manufacturer and from where the raw materials were harvested. Other materials, like Division 06 plastics, only need to be manufactured within the given maximum distance.

Because of their harm on health and the environment, there is a list of materials and chemicals, known as the Red List, that cannot be used in Living Building Challenge Projects. Few exceptions are made based on alternative material availability and cost. These materials include:

- Asbestos
- Cadmium
- Chlorinated Polyethylene and Chlorosulfonated Polyethlene
- Chlorofluorocarbons (CFCs)
- Chloroprene (Neoprene)
- Formaldehyde (added)
- Halogenated Flame Retardants
- Hydrochlorofluorocarbons (HCFCs)
- Lead (added)
- Mercury
- Petrochemical Fertilizers and Pesticides
- Phthalates
- Polyvinyl Chloride (PVC)

- Wood treatments containing Creosote, Arsenic or Pentachlorophenol

There are temporary exceptions for numerous Red List items due to current limitations in the materials economy. The Living Building Community Dialogue is a web-based interactive tool for complete and up-to-date listings (ILBI 2010).

Case Studies

Tyson Living Learning Center

Figure 1: Tyson Living Learning Center at Washington University in St. Louis (ILBI 2010).

This Living Learning Center is part of the Tyson Research Center at Washington University in St. Louis and is certified 'Living' through the International Living Building Institute. What used to be a degraded asphalt parking lot is now an educational center with native landscaping, pervious concrete, and a central rain garden. The project covers 25,000 square feet with a 2,700 square foot building (ILBI 2010).

The research center builds on the sustainable ecosystem research going on at Tyson. It is made of wood, all of which was harvested on the Tyson property. The trees used were already down from storms or dead, or considered invasive to the area and were going to be removed for ecosystem improvement. Almost 100 percent of the wood used on the project was obtained sustainably within a two-mile radius. A challenge faced in meeting the material requirements for LBC was finding certain materials, like light fixtures and door hardware, that were manufactured in the region with sustainable manufacturing processes. Many materials were salvaged from past projects in the area, making the building less expensive and more sustainable (Washington University in St. Louis 2008).

It achieves net zero energy through the use of photovoltaic panels with 20.3kW production capacity and high building efficiency. Some of the methods used to increase efficiency are building orientation, high R-value insulation, utilization of natural ventilation and daylight, and high efficiency appliances, lighting, and HVAC systems. Variable capacity heat pumps are used to provide just enough heating and cooling to keep the building at a comfortable temperature. Large glass overhead doors can be opened during nice weather to combine the classroom and deck, increasing ventilation throughout the building and providing ample natural light. Water is treated through composting toilets and infiltration gardens (Washington University in St. Louis 2008).

LEED versus Living Building Challenge

LEED was created by the national organization, USGBC, while LBC was created by the international organization, ILBI. However, both programs are used internationally in multiple countries. LEED has projects in progress in 120 different countries, a much wider area than LBC, which currently only has projects built or planned in the US, Canada, Ireland, Australia and Mexico.

Both LEED and the Living Building Challenge have an overarching goal of reaching a sustainable future with sustainably built structures and infrastructure, as well as sustainable practices used by all businesses and consumers. LBC and LEED strive to reach this common goal through different means. LEED focuses on improving the sustainability of structures, while LBC requires a high level of sustainability for each project to preserve and possibly restore the environment. The requirements for LEED are detailed, some describing certain performance levels and some outlining specific practices or materials to be used. LBC requirements are broader and performance-based. This is meant to promote innovation of new sustainable techniques so the field can continue to grow with each project created. LBC also has more extensive requirements of working with regional companies and companies using sustainable practices. This is part of their view that just improving sustainability in some areas is not enough to counteract the damages done to the environment. LEED gives credit for percentages of energy reduction and renewable energy used while LBC requires net zero energy for the project. Similarly in materials, LEED provides credit for percentages of local renewable materials and recycling material. LBC goes beyond this to also include a list of harmful materials that cannot be used with few exceptions when there are no material alternatives, which require other means to increase community sustainability.

The LEED rating system consists of basic sustainable requirements that must be met and numerous optional credits, while LBC projects must meet all imperatives in the LBC for that type of project. LEED has a large range of certification levels depending on the extent of sustainable practices used and credits earned, while LBC certification can only be achieved if all imperatives are met. This allows LEED to be used for a wide variety of project type and size including single homes, large businesses, hospitals and neighborhood communities, while LBC is limited to small buildings, small renovations and landscaping or infrastructure. It is also more challenging to achieve LBC certification because the project must be operational for at least 12 months before performance-based measurements are taken, while LEED certification can be done before the project goes into operation because it is based on expected performance.

As LEED is becoming more common and more developers desire sustainably built structures, many engineers are getting trained in LEED. This large number of people knowledgeable in LEED allows for widespread training in LEED communities around the world that wish to create LEED certified structures. LBC also has international influence, but has not grown large like LEED has, limiting the number of people for training around the world.

Sustainable Design Programs in Chile

Chile has a green building council that is working to become a member of the World Green Building Council. Their mission is to "To promote and encourage the construction and sustainable development in Chile, as well as the efficient use of energy and reducing emissions of greenhouse gases (GHG) emissions and other environmental impacts, improving the quality of life of individuals and communities" (Chile GBC 2011).

LEED has a large presence in Chile with 11 certified projects and over 120 registered projects (LEED Project Directory 2011). The Chile GBC is working to put forward Chile LEED standards based on the LEED standards for new construction in the United States that will be successful in the Chilean market. So far they have put together the sections on credits in water efficiency and in materials and resources. Next will be documents pertaining to energy efficiency, sustainable sites, and indoor environmental quality.

In the LEED Materials and Resources document, all the same credits as previously discussed are included. Point breakdowns for LEED certified schools and core and shell rating systems are also given. Also included are recommendations of which members of the project team should get involved, and multiple in-depth methods for obtaining each credit that the Chile GBC believes will work best in the Chilean market. They also include descriptions of several ways to verify that the project will meet each LEED credit (Materiales y Recursos 2011). Each credit is broken down into sections. Credit 1.1, Building Reuse, is described briefly with the intention and requirements, and then broken into building framework, historical buildings, and industrial buildings, each with suggestions about how to best reuse parts of the building. Credit 2, Construction Waste Management, is broken down into creating a plan for managing construction debris, diverting waste from landfills, taking waste to recycling centers, and managing hazardous waste. For credit 5, Regional Materials, maps, like the one shown in Figure 2, are given to show what materials are local in the different regions of Chile (Materiales y Recursos 2011). This will be extremely helpful when designing projects to see if there are local materials available that are usable for the given project, and to know what materials should be used in the design to make it as sustainable as possible. Credit 6, rapidly renewable materials, gives examples of rapidly renewable materials including bamboo, cork, cotton, straw and wool, and the best uses for them in

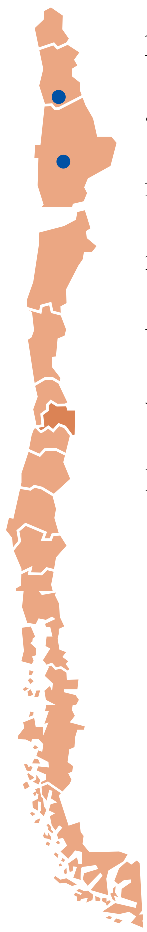

Figure 2: Location of natural aggregate sources in Chile (Materiales y Recursos 2011).

construction. It also lists local production industries for each material type listed. For credit 7, Certified Wood, it lists different companies that produce certified wood and what types of wood products they make.

In the appendix of the Materiales and Recursos document, methodologies for each credit are discussed in more detail. Examples of existing LEED certified projects from around the world are given, along with a description of what they did to achieve that credit. For the Construction Waste Management credit, regulations and the applicable articles within them are listed, along with websites where the full regulations can be accessed. Related documents still in the legislation process are also mentioned with a website to access information about them, and how regulations will change once they are made official (Materiales y Recursos 2011).

Programs in the United States Compared to those in Chile

While the basic information given in LEED documents in the Unites States and Chile is the same, there are some significant differences due to the intended audience and purpose of the documents. First, Chile GBC is putting forth a new document for each of the five sections of LEED credits, whereas the US GBC has one document to include all sections. While both documents include intent, requirements, and potential strategies to achieve that point, the Chile document also includes methods of validation of the LEED credits. It also goes into descriptive detail for potential strategies and verification methods to achieve each credit, whereas the US document simply lists a few potential strategies. The Chile document also includes color, pictures, and tables to aid in the descriptions.

In Chile, LEED has a much smaller presence and history than it does in the United States. The current Chile LEED documents are the first official versions to be released. One of the main goals of the Chile GBC in producing these documents is to promote the education and use of LEED. Their document is eye-catching and interesting to a reader, as well as understandable for those with little knowledge of the LEED certification program. The detailed descriptions for methods will greatly assist project teams that are new to LEED and need ideas of how to achieve LEED points. Examples of existing projects and their methods for achieving LEED certification are also given. Having these resources will also encourage project teams to pursue LEED certification because it will be less overwhelming and seem more feasible. Currently the Chile LEED documents are only produced in Spanish, which may be an obstacle if there are people working on the LEED design elements for a project in Chile that do not speak Spanish.

In the United States, LEED has been around for years and is used by many engineering firms. Thousands have become LEED professionals at different levels. Because of this high level of understanding and experience, The US LEED documents have a different goal than those in Chile. Their main purpose is to give the basic information in a concise format about what is needed for each credit. Brief potential strategies are given, but without any detail examples of existing LEED projects. This is most likely based on the assumption that many of these strategies are already known based on previous experience or the knowledge of other team members. Also, with less description of how to achieve the credit, team members are less likely to limit themselves to just those solutions. This will help promote the goal of the GBC to continually create new and innovative ways to achieve sustainable design.

Chile does not have any programs like the Living Building Challenge, and the LBC has yet to become a part of sustainable design in Chile. The sustainable design movement in Chile is still fairly new, and many do not see the necessity of truly sustainable design like buildings done for the Living Building Challenge. Many project owners seeking LEED certification do so to have the certification, not necessarily to have a sustainable project (Araya 2012).

SUSTAINABLE MATERIALS

Using sustainable building materials can make a significant impact on the sustainability of a project. It is estimated that 10 to 12 percent of carbon dioxide emissions in the U.S are from building supplies, the majority of which is from the energy needed to create them (Voith 2010). Sustainable building materials can decrease CO_2 emissions, conserve natural resources, and reduce waste from demolished structures. This thesis will focus on recycled concrete aggregates and cement alternatives used in concrete and wood as sustainable materials.

Sustainable Materials In The United States

Recycled Aggregate Concrete

Concrete is the most common material used in construction, being used more than two times all other materials combined (Kosmatka and Wilson 2011). Traditional concrete has the potential to be made more sustainable by reducing the amount of CO_2 emissions from obtainment and production, as well as reducing the waste material from its life cycle. Virgin aggregate is harvested from quarries and sometimes transported long distances before being processed into concrete.

Recycled aggregate, RA, is often used to replace the natural coarse aggregate, NA particles in concrete. This can be created from parts of demolished concrete structures including slabs, beams, and walls. A challenge with these is determining properties of the aggregate since the original mixture and strengths, as well as changes in its properties during its use are often unknown. Several tests are typically done according to BS 812: 1992 to test properties like flakiness and elongation, water absorption and specific gravity, and aggregate crushing and impact values (Rahman 2009).

Many researchers find recycled aggregate has low workability and compressive strength because of multiple factors including smooth texture, rounder shape, higher percentage of fine particles, and high water absorption. Researchers at Hong Kong Polytechnic University found a higher compressive strength in recycled aggregate concrete, claiming that recycled aggregate has a more angular shape and rougher texture than natural aggregate. They recommended oven drying the recycled aggregate to create the interfacial bond between cement and aggregate (Rahman 2009).

An experiment was done at the University in Jahore, Malaysia that showed recycled aggregate concrete has similar compressive strength characteristics to natural aggregate concrete (Rahman 2009). As seen in Table 2 below, the recycled aggregate had lower flakiness and elongation indices. As in previous research, the water absorption was found to be higher in recycled concrete than natural concrete. However, this decreased significantly as the size of the aggregate decreased. Oven-dried specific gravities were the same for the recycled and natural aggregate. The recycled aggregate crushed more easily than the natural aggregate, but not by a significant difference and the crushing index was still below 30 percent. As seen in Figure 3 below, the recycled aggregate concretes had lower slump values than the natural aggregate concretes, showing they have lower workability. All tested values for the recycled aggregate are below the limits of the standard, so it is suitable for use as the coarse aggregate in concrete.

Table 2: Physical properties of the recycled and natural aggregates (Rahman 2009).

Test	RA			NA
	10mm	14mm	20mm	
Bulk Specific gravity	2.36			2.41
Specific gravity (SSD)	2.40			2.45
Specific gravity (apparent)	2.51			2.51
Water absorption (%)	1.39	1.78	3.48	1.67
Aggregate impact value (%)	31.70			31.70
Aggregate crushing value (%)	28.57			16.33
Flakiness index (%)	19.40			38.35
Elongation index (%)	11.30			39.12

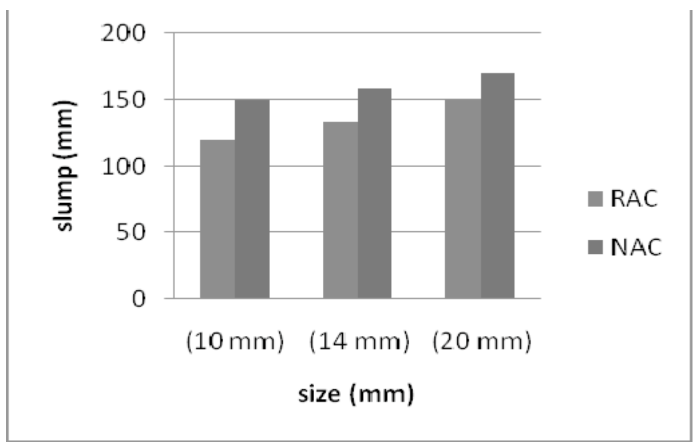

Figure 3: Slump values of RAC and NAC (Rahman 2009).

In this experiment, performance of the concrete was also tested. Concretes with recycled aggregate and natural aggregate were mixed for a design compressive 28-day strength of 25MPa. Different mixes were made with 10mm, 14mm, and 20mm maximum aggregate sizes. Compressive strength was taken at 3, 14, and 28 days, all with similar results. As seen in Figure 4 below, the compressive strength of the RAC and NAC were very similar for the 10mm aggregate. As the aggregate size increased, the strength of the NAC significantly increased to 36MPa for 20mm aggregate, while the RAC strength barely increased to a strength of 27MPa for 20mm aggregate.

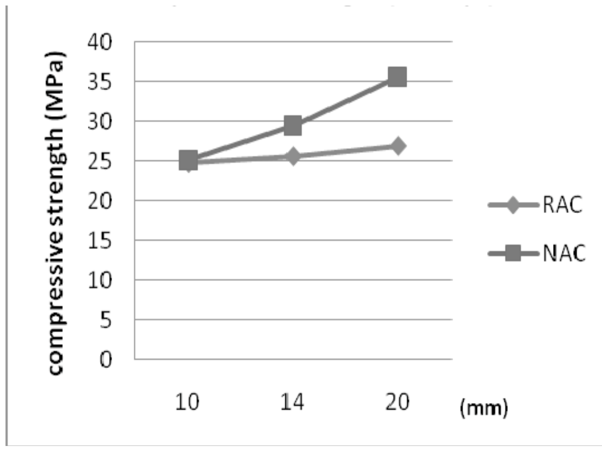

Figure 4: Compressive strength of RAC and NAC (Rahman 2009).

This experiment, along with other research, showed that recycled aggregate concrete can decrease strength in concrete. However, it still reaches strength values and has characteristics suitable for concrete. In other research, recycled aggregate always had higher water absorption than natural aggregate (Rahman 2009). Testing of the recycled aggregate properties before use in concrete can help determine if it is suitable for concrete in a specific construction project, based on necessary strengths and dimensions. It can also determine if that RA does not meet any requirements like water absorption limits. Knowing properties of the recycled aggregate can also help determine what additives may be needed so it can achieve the necessary performance.

Cement Alternatives

Another way to increase the sustainability of concrete is through alternatives to the cement. Some companies are looking at ways of reducing the high amount of energy needed to create products like cement. Portland cement, the most common worldwide cement type, is one of the main targets of these companies for reducing the carbon dioxide footprint of building materials. According to the World Business Council for Sustainable Development, cement manufacturing is responsible for 5 percent of global CO_2 emissions (Voith 2010). Its production also accounts for 2-3 percent of global primary energy use (Juenger et al 2010). Cement often includes waste products like fly ash from coal production and blast furnace slag from iron production, but these are only used for 10-50 percent of the cement (Juenger et al 2010). Methods are being researched to create cement that is almost if not entirely made from waste material from other common and necessary processes, and to reduce the energy demand and greenhouse gas emissions from its production.

Cement alternatives being developed must be researched enough to have a strong basic understanding of their performance (especially long-term durability), processing, and chemical and physical behavior. Once this is complete, performance and composition parameters must be included in relative standards and specifications. Another obstacle is getting the cement alternative accepted and used in the construction industry. However, the biggest obstacle is cost. Since cement and concrete are produced at such a large scale and relatively inexpensively, any alternative cement will not only have to compete on a performance basis but also on a cost basis. Cement alternatives with multiple advantages over Portland cement will be more easily incorporated into the construction industry. Four alternatives that show promise for entering the market as Portland cement alternatives are calcium aluminate cement, calcium sulfoaluminate cement, alkali-activated binders, and supersulfated cement (Juenger et al 2010).

Calcium aluminate cements (CACs) contain primarily monocalcium aluminate and produce less CO_2 during production than Portland cements. They also have rapid strength gain once set and are resistant to abrasion, sulfate attack and alkali-silica reaction (Juenger et al 2010). These factors are helping CACs gain prominence in the construction industry. However, they do have some disadvantages, mainly being a higher cost associated with the limited supply of alumina source and an increase in porosity over time due to hydrate conversions (Juenger et al 2010).

Calcium sulfoaluminate cements (CSA) contain ye-elimite, which is often an addition to cement to compensate for shrinkage. Calcium sulfate is also added to obtain rapid-hardening, high strength, expansive cements. They have low pH and porosity, and can bind with heavy metals. They also emit less than one half the CO_2 of conventional portland cements during the cementing phase, and require less energy for clinker production because of lower heating temperatures and easier grinding (Juenger et al 2010). Studies show that the durability of concrete containing CSA cements is comparable to portland cement concretes, though more long-term studies are needed to verify this. Like CACs, CSA can be produced from bauxite as an alumina source, which has a limited supply, making CSA more costly than portland cement. Alternative alumina sources, especially those from waste materials, are being explored to lower this cost.

Alkali-activated binders also have high strength and low environmental impact relative to portland cement, as well as high durability. These are produced from mixing an alkaline-activating solution with aluminosilicate powders like fly ash or blast furnace slag.

Substituting these binders for portland cement can reduce CO_2 emissions by 80 percent or more (Juenger et al 2010). Studies have shown alkali-activated binders to have comparable or better physical properties than Portland cement (Juenger et al 2010). The properties of these binders are sensitive to the activation conditions, though engineering technologies are advancing to make the activation simpler and more accurate. This sensitivity includes the durability of the binder. Like other alternatives, these binders are more costly than portland cement because of the current limited production of alkali-activators (Juenger et al 2010).

Supersulfated cements are generally comprised of blast furnace slag, calcium sulfate, and an alkaline activator, often portland cement, which is typically less than 5 percent of the overall mixture. Due to their low porosity and high aluminate content, supersulfated cements have high durability and high resistance in chemically aggressive environments (Juenger et al 2010). Strength development is slower in supersulfated cements than in portland cement, however, the 28-day strengths are comparable. With the slow strength development and possibility of carbonation, supersulfated cements require prolonged moist curing (Juenger et al 2010). A comparison of these alternatives to portland cement can be seen in Table 3 below.

Alternatives such as these have been studied for decades, but still only used on a small scale in certain applications. This is primarily due to the higher cost compared to portland cement and the reluctance of the construction industry to change their materials and procedures. The use of these cement alternatives will likely increase as product specifications and standards become more widespread and in-depth.

Table 3: Comparison of alternative binders to portland cement (Juenger et al 2010).

	Portland cement	Calcium aluminate cement	Calcium sulfoaluminate Cement	Alkali-activated binder	Supersulfated cement
Primary phases/materials	C_3S	CA	$C_4A_3\bar{S}$, C_2S, $C\bar{S}$/$C\bar{S}H_2$	Aluminosilicate, alkali	Slag, $C\bar{S}$/$C\bar{S}H_2$
Secondary phases/materials	C_2S, C_3A, C_4AF, $C\bar{S}H_2$	$C_{12}A_7$, CA_2,C_2S, C_2AS, C_4AF	C_4AF, CA, C_2AS		Alkali/Portland cement
Hydrates	C–S–H, CH, AFt, AFm	CAH_{10} (m*), C_2AH_8 (m), C_3AH_6, AH_3	AFt, AH_3, AFm, C_2ASH_8, C–S–H	Gel (N–A–S–(H) and/or C–(A)–S–H), zeolites, hydrotalcite	AFt, C–S–H, AFm, hydrotalcite
Raw material CO_2 (g/g) primary phase [36]	$C_3S = 0.578$	$CA = 0.279$	$C_4A_3\bar{S} = 0.216$ $C_2S = 0.511$	Activator NS = 0.361	0
Clinkering temperature	~1450 °C	>1450 °C	1250 °C	Fly ash/slag: N/A Metakaolin: 800 °C	N/A
Grinding energy (kWh/t)	30 [144]	>30 [9]	~20 [145]	Slag: 50 [146]	Slag: 50 [146]
Advantages	—Long history —Standard compositions	—Rapid strength —Sulfate resistant —No alkali–silica reaction —Abrasion resistant	—Low CO_2 —Low energy —Rapid strength —Shrinkage compensating	—Low CO_2 —Low heat of reaction —Heat and acid resistant	—Low heat of hydration —Durable in aggressive environments
Disadvantages	—High energy —High CO_2 —Limited early strength —Poor in aggressive environments	—Strength loss on conversion of metastable to stable hydrates	—Durability unproven —Sometimes expansive	—Sometimes slow strength gain —Caustic activating solution —Challenging rheology —Durability unproven	—Slow strength gain

m* = metastable.

Calera Corporation, a clean technology company in California, is researching alternatives to cement and aggregates in concrete. Professor Brent Constantz at Calera is working to change the concrete production process to have an overall negative CO_2 footprint (Voith 2010). This process consists of bubbling CO_2 gas through seawater or hard water to create calcium and magnesium carbonates. These precipitates are transformed to a synthetic limestone aggregate and an amorphous calcium carbonate with cement-like properties to be used in concretes. This process is similar to the process used by coral to precipitate carbonates from the ocean. Calera estimates that this new concrete absorbs 1,000lb of CO_2 per cubic yard of concrete, compared to traditional concrete that generates more than 500lb of CO_2 per cubic yard of concrete (Voith 2010).

A challenge for this new concrete design is the necessary conditions for the carbonates to precipitate. The solution to which CO_2 is added must have a high pH. When necessary, Calera is proposing to use a low-energy electrochemical process to add alkalinity to the water. Another challenge will be creating sufficient carbonates. Selecting an appropriate sight can help this. The ideal sight would have a CO_2 producer, like a power plant, a concrete ready-mix plant, and a water desalination plant. This would provide ample CO_2 and not require transportation to create the concrete. Also, the water, after calcium and magnesium are removed, could be inexpensively desalinated. What salts are removed can be sent back through the system to create more carbonates (Voith 2010).

Wood

Wood can be a valuable renewable resource. However, if not harvested in a sustainable manner, the negative environmental impacts can be significant. Using recycled wood instead of freshly harvested wood reduces the CO_2 emissions produced by the harvest and allows the un-harvested trees to continue absorbing CO_2.

There are several factors decreasing the use of wood as a primary construction material. One factor is concerns of lifespan and sound insulation. Another is the variability in the strength of different wood members. There is also the concern of deforestation if the forests are not managed sustainably. Also, many engineers and architects are trained in more common building materials like steel and concrete, and do not have the expertise to design timber structures. Construction workers are also often less familiar with wood building, increasing construction time and cost, as well as liability. There is also the misconception that wood is always a high risk for fire events, when in actuality large wood structural members will hold strength properties better than steel in fires. The marketing of wood as a construction material is also much lower than that of concrete, steel and plastic (Gustavsson et al. 2004).

Most wood used for structural members in construction will need to be of a certain quality. Wood used for particleboards has less stringent standards, greatly increasing the availability of the raw product. Engineered wood products, like glulam, I-beams, and veneer lumber, are increasingly prevalent as large solid sawn lumber availability is decreasing.

Substituting wood for other construction materials like concrete and steel can reduce greenhouse gas emissions both because it is less energy intensive to produce and because wood residue from logging, processing, and deconstruction at the end of its use can be used for a lower CO_2 emitting form of energy generation than using fossil fuels. One study done on roofing construction showed that the manufacturing of steel beams uses two to three times the energy of manufacturing glulam beams (Gustavsson et al. 2004). However, these results were highly dependent on assumptions made about manufacturing and waste handling processes, as well as obtaining the raw material. Another study on multi-story apartment buildings showed that the production of materials for wood-framed buildings required less energy and emitted less CO_2 than the production of concrete for similar concrete-framed buildings. These results were repeated through multiple different scenarios, though had varying levels of reduced CO_2 emissions (Gustavsson et al. 2004). This study did not include economic considerations, but instead assumed that the timber structure would be competitive in quality and economy with a similar concrete-framed structure.

Another study done compared a four-story wood-framed apartment building with a concrete-framed design for the same building. The two frames were analyzed for primary energy use, and CO_2 and methane emissions through the material life cycle from recovery of raw material to the final deconstruction and disposal (Borjesson 2000). The main contributors for greenhouse gas emissions in this analysis were fossil-fuel consumption during production, changes in biological carbon stocks in the forest, methods for demolition of wood, and CO_2 emissions during cement production and carbonization of the concrete.

The energy use and CO_2 emissions during building operation were not included, as they were calculated to differ by less than one percent between the buildings with different framing materials (Borjesson 2000).

Energy demands for material production were calculated based on averages for different manufacturing processes. This study found that the use of concrete frames would increase the amount of primary energy used in production by about 60-80 percent compared to the wood frame, depending on whether natural or crushed gravel was used in the concrete. This is seen in Figure 5 below.

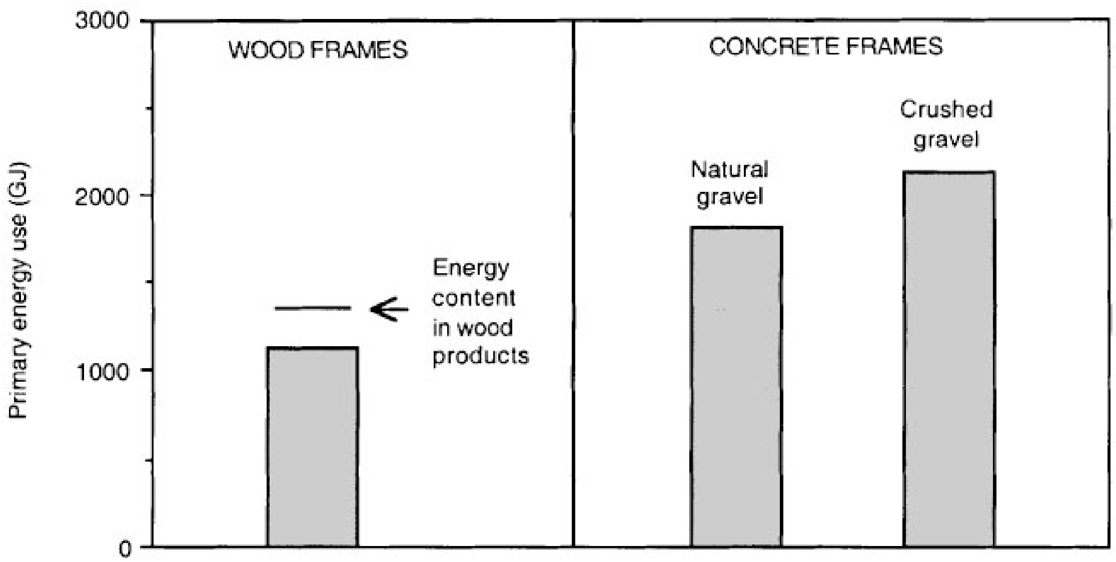

Figure 5: Primary energy use in the production of building materials (Borjesson 2000).

Greenhouse gas emissions from the building were analyzed for a 250-300 year period. period. This included fixation of CO_2 by tree growth when wood was not harvested for the wood frame, emissions from fossil fuel used in material production, CO_2 re-bound in the carbonization of harden concrete, and the emission of CO_2 from decomposing wood or the reduction of CO_2 emissions if the wood is used for energy generation in place of fossil fuel at the

the end of its life cycle. The study showed that net CO_2 emissions were about 1.5 – 2 times higher for the concrete frame than the wood frame when carbonization of concrete and use of waste wood as energy are not included in the net calculations. Including carbonization would would lower the difference, but adding re-use of wood products as construction materials or for for energy generation would make the emissions several times higher for concrete.

Figure 6 and Figure 7 below show the carbon equivalents of the net greenhouse gas emissions for the wood and concrete frames for emissions from material production, different end uses of the wood, and both including and not including carbonization of the concrete. The carbon equivalents for wood include 32 t of carbon emitted during production. The carbon equivalents for concrete include 90-105 t of carbon emitted during material production and -30 t of carbon from replacing fossil fuels with energy generation from the amount of wood that would have been used in the wood-framed building (Gustavsson 2000).

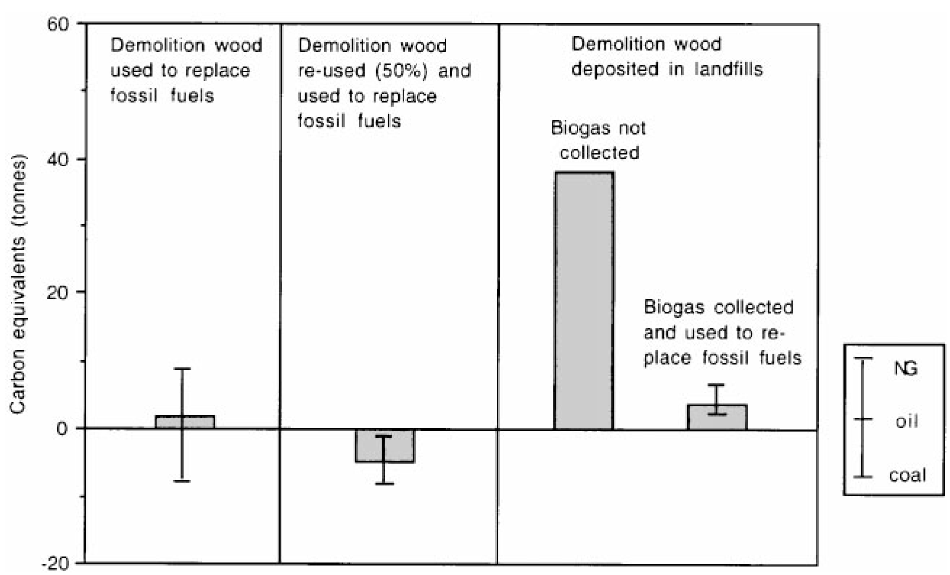

Figure 6: Net CO_2 emissions from wood life cycle (Gustavsson 2000).

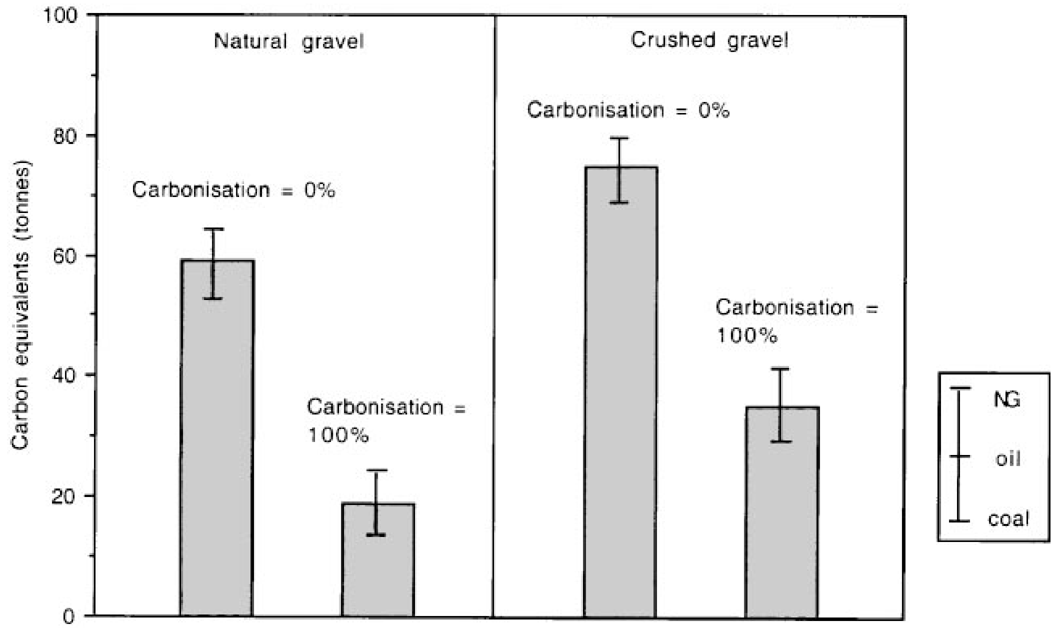

Figure 7: Net CO_2 emissions for concrete life cycle (Gustavsson 2000).

This study shows that wood as a structural material can produce much less greenhouse gas emissions than concrete. However, the cost data used was limited to a few studies. Further investigation should be done to assess the quality of the input data and to look at other cost data from similar building material studies. Also, this comparison may need to be reanalyzed as manufacturing processes and technologies become more efficient. This study also did not include an economic analysis of the different construction materials. A similar study looking at full life cycle analysis and life cycle costing could be done to further analyze the differences in concrete and wood structures in terms of cost and effect on the environment.

Using wood as a construction material and energy source will greatly increase the demand on forests. These will need to be managed sustainably in order to keep wood as a sustainable renewable resource. Forest rotation periods are typically around 100 years, though they could be increased by 2 – 4 times with new forestry methods like optimized fertilization (de Bonafos 2001). One way to assess efficiency in greenhouse gas mitigation of forest management is to express the emission reduction per unit area of forestland.

Sustainable Materials in Chile

Recycled Concrete Aggregates

Recycled concrete aggregate has also been researched in Chile. Natural aggregates are only available in small regions in the northern part of Chile (Materiales y Recursos 2011). Recycled concrete aggregates would be a valuable alternative, especially in urban areas where concrete from demolished buildings and roads is available. This would also significantly reduce transportation costs for obtaining natural aggregate either from northern Chile or from another country.

The University of Santiago did a study in 2004 to compare the physical properties of fresh concrete with concrete made with recycled aggregate from demolished concrete structures (Aguilar et al 2005). Both concrete mixes were made with portland cement. Two concrete mixes were made with recycled concrete aggregate, one from demolished laboratories and one from demolished pavement. Table 4 below shows the physical properties of the three aggregates used in testing.

Table 4: Physical properties of the various aggregates used (Aguilar et al. 2005).

Property		Natural Aggregate Gravel	Sand	Recycled Aggregate from laboratory concrete	Recycled Aggregate from demolished concrete pavement
Particle Shape					
Crushed	%	70	-	83	97
Round	%	25	-	15	1
Elongated	%	5	-	2	2
Density					
Loose weight	kg/m^3	1510	1657	1313	1297
Compacted weight	kg/m^3	1597	1721	1396	1441
SSS density	kg/m^3	2630	2630	2530	2540
Dry density	kg/m^3	2610	2560	2430	2440
Net density	kg/m^3	2650	2730	2700	2710
Water absorption	%	0.6	2.4	4.1	4.1
Voids					
Loose	%	43	35	46	47
Compacted	%	39	33	42	41

This table shows that the recycled concrete aggregate had much higher levels of water absorption than the natural aggregate. These values could be due to the water absorption of the cement adhered to the recycled concrete. These values must be taken into consideration if this recycled concrete were to be used in a new concrete mix.

The results showed a decrease in all physical properties for recycled concrete aggregate compared to the natural aggregate. They also found diminished strength and modulus of elasticity in concrete made with recycled concrete aggregate. Based on the results, they concluded that the diminished strength capacity and physical properties of the concrete with recycled aggregate was due to the cement adhered to the surface of the recycled concrete aggregate (Aguilar et al. 2005).

Wood

Wood is available throughout Chile. There are more than 13 million hectares of native forests and 2 million hectares of pine plantations. This provides Chile with a harvesting potential of 48.3 million cubic meters of wood annually (de Bonafos 2001). The challenge is to use this resource in a sustainable manner. Wood is a large export for Chile, which increases the possibility of over-logging and deforestation. There have been multiple debates between environmentalists and timber companies over certain forested areas and whether they should be logged or preserved.

Certification is one method that has been proposed for protecting forested areas from getting over harvested. The ultimate goal of implementing forest certification is working towards economic, environmental, and social sustainability in the forestry industry (de Bonafos 2001). Some argue that this will be counterproductive for the export industry, while others see it as a necessity. Many large companies are voluntarily achieving certification because they see it as a necessity to stay globally competitive. Small companies are more reluctant because they cannot afford the time and money necessary to implement certification systems like the Forestry Stewardship Council (FSC) principles and ISO standards. Less expensive and less complex national standards are being developed to help Chile keep up with global competition. These standards however, are being developed with large plantations in mind (de Bonafos 2001). This is leaving the large number of small forestry businesses behind to continue unsustainable business practices. The certification process in forestry needs to work towards the goal of sustainability and encouraging forestry businesses to pursue sustainable practices in order to protect the environment, and not just to stay globally competitive.

Materials that Can Be Better Utilized in Chile

Recycled concrete aggregate can be an important material in moving towards sustainability. Concrete can be found almost anywhere in roads, buildings, and smaller applications. Recycling concrete when it is demolished aids in reducing construction waste, conserving natural resources, and saving the energy and greenhouse gas emissions that would occur if natural aggregate needed to be extracted. This is a viable solution for sustainable building projects in Chile, especially with natural aggregate production limited to the northern most regions of the country. Concrete is a common building material that most engineers and contractors are experienced in using and designing.

Research, like that presented here from the University of Santiago, can have a significant impact on what is used in the market. Many firms do not have much experience or knowledge dealing with recycled concrete, so they will depend on research to determine if it is a good option in design. Studies showing that concrete with recycled concrete aggregate has lower strength values compared to concrete made with natural aggregate will discourage people from using it, especially if natural aggregate concrete is readily available. These designers need to also consider the negative environmental impact of using natural aggregates, possibly from distant regions, and allowing the demolished concrete to be wasted instead of reused. As more research is done in Chile and worldwide research becomes better known in Chile, recycled concrete aggregate should become more widely used. Along with research, Chile needs to develop specifications and practical design guides for materials like recycled concrete aggregates. These will make it easier for designers and contractors to use these materials in their projects.

The use of cement alternatives can also greatly improve the sustainability of concrete structures in Chile. The recycled concrete aggregate study presented here only used portland cement. Certain cement alternatives as discussed above can help increase the strength and durability of the concrete, which can make the recycled concrete aggregate more comparable to natural aggregate in concrete mixes.

With the large wood resource in Chile, wood could be a viable option for a sustainable material. This would be more difficult to promote because of the reluctance of environmentalists to cut down more forests. Certification and documentation would need to be put together showing that the wood used in sustainable projects was also harvested sustainably and not destroying the forests. With wood being a large export for Chile, the increase in use of wood as a construction material in Chile would have to be monitored closely so as to prevent any negative effects on the Chilean economy from possible limited wood exports. This result would frustrate forestry companies as well as everyone negatively affected by the economic changes, resulting in a negative attitude towards sustainable building. This would hinder the Chile Green Building Council's goal of promoting and educating people about the importance of sustainable design.

CASE STUDIES

Stapleton Denver International Airport

Figure 8: Stapleton Community (Northfield Stapleton 2011).

When the old Stapleton International Airport in Denver was renovated, sustainable design was priority. "‘In Stapleton, we've worked to create a community that is founded on sustainability,’ said Denise Gammon, Senior Vice President of Development for Forest City Stapleton, the master developer of the Stapleton Community” (Yarborough 2010). The airport is now a neighborhood with 12,000 homes, 6 schools, and an 80-acre central park. There are also 930,000 square meters of office space and 280,000 square meters of retail space. The total area of parks and open space is 4.5 million square meters. This includes Sand Creek Regional Greenway and Bluff Lake Nature Center. In the park areas, prairie and riparian corridors have been restored. There are also extensive bike trails, existing and planned transit services, and mixed use destinations which reduce traffic congestion and pollution (Carder 2011).

Many elements of this project fall under sustainable design. All homes meet or exceed Energy Star standards. There is 40 to 70 percent savings in energy, water and other resources when compared to conventional design and construction (Carder 2011). The layout is created to reduce travel distances for residents in order to reduce traffic and the pollution caused by it. The asphalt and concrete removed was about 5.5 million tonnes and covered 4 million square meters (Carder 2011). Some of this concrete was recycled and used for the redesign of the airport, while the rest of it was reused in local building projects, including the foundations of office buildings and warehouses in the local area (CMRA 2012).

Parts of the Stapleton community were designed for LEED certification, some of which are still being certified. Northfield Stapleton, the main shopping district, achieved a LEED silver rating with a score of 30 out of a possible 69 points. This included achieving 5 out of 11 points in the Materials and Resources section. It also included all 5 possible points in the Innovation & Design Process section. This center incorporated skylights in their design for increased natural lighting and occupancy sensors to turn down lights when not needed. Recycling was also a large part of the Stapleton project. Northfield recycled over 2,300 tonnes of waste during construction (Northfield Stapleton 2011). Local materials were used for building construction whenever possible. Much of this material came from the original Stapleton airport. Concrete from the runways was recycled to make new concrete, and aluminum signs were reused for new signs around the mall. Northfield received LEED credits for reusing at least 5 percent of onsite material resources, using materials containing at least 10 percent recycled content, and using 50 percent materials that were harvested locally. The building also features a reflective roof and energy efficient windows and fixtures (Northfield Stapleton 2011).

Titanium Tower

The Titanium Tower in Santiago, Chile achieved a LEED gold rating for Core and Shell, receiving 41 out of a possible 60 points. In the Materials and Resources section, 3 of 11 points were obtained. All 5 of the possible Innovation in Design points were obtained. The Titanium Tower is a large commercial and office building with 52 floors, 7 underground levels and 122,000 square meters of total area (Titanium La Portada 2008). It uses a system of three elevators, each of which take people to a different third of the building floors. Its framework is made up of large reinforced concrete columns, pre-tensioned concrete beams and reinforced concrete slabs. The thin design of the structure provides ample ventilation through the building. The design was highly energy efficient, reducing the total energy demand to 95 kWh/m^2, compared to a standard building of similar size, which would use 400 kWh/m^2. The tower design was estimated to reduce carbon emissions by 35 percent, reduce water use by 30-50 percent, and reduce waste and associated costs by 50-90 percent (Titanium La Portada 2008).

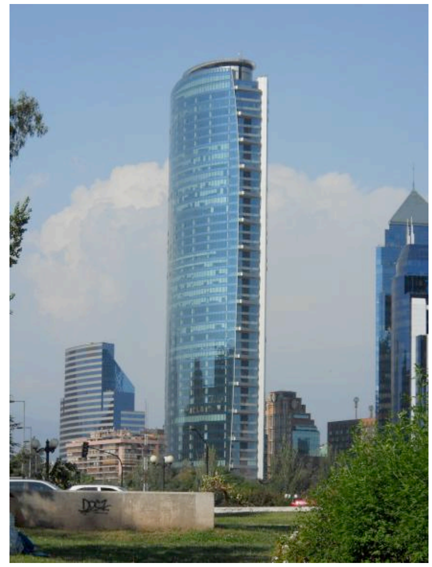

Figure 9: Titanium Tower (Titanium La Portada 2008).

This tower was designed by Miranda & Nasi Consultants, an engineering firm in Chile that promotes green building and has done several LEED certified projects, including 6 already certified projects and 50 projects in the process of certification (Miranda & Nasi 2012). These projects vary in application, with multiple projects in each of the LEED rating systems.

Costanera Center

Figure 10: Costanera Center (Herrera and Almendras 2008).

The Costanera Center in Santiago, Chile is expected to achieve a LEED Gold rating for Core and Shell (Materiales y Recursos 2011). This center consists of four towers and several small buildings that will include office, retail, and residential space with a total of 694,000 square meters of area. There will also be five underground levels of parking. This added up to 30,000 cubic meters of concrete and 85,000 tonnes of steel used for the project (Herrera y Almendras 2008). The main tower will become the tallest building in South America at 300 meters (Alemparte Barreda 2010).

This project includes multiple sustainable aspects to achieve gold rating. One of the design elements for the materials and resources LEED credits is that it used recycled steel in much of its framework (Materiales y Recursos 2011). The project also has a construction waste management plan to control dust and gas emissions. There is also a green roof over several of the buildings, providing 20,000 square meters of green roof for absorbing and storing rainwater (Costanera Center 2012). The towers were designed to be energy efficient and use water from a nearby canal as a cooling system. There are also multiple systems to control energy and water use. The exterior of the main tower uses glass panels with aluminum framing to provide ample natural light to the building and cut down on energy use for lighting (Herrera y Almendras 2008). Concrete was mixed on site and produced at a rate of 360 cubic meters per day (Herrera y Almendras 2008). This prevented the need for several concrete trucks continually shipping concrete from the manufacturer.

LIMITATIONS

Economy And Living Standards in Chile

In 2001, one in four people in Chile lived in poverty (Larrain 2001). The economy is growing from large exports of natural resources, but this is not creating new jobs because of increasingly mechanized processes. It also is significantly decreasing the available natural resources and causing pollution problems in the country due to greenhouse gas emissions caused by traditional extraction processes of natural resources. The Sustainable Chile Program (SCP) created a project analyzing all social, environmental, and political problems, and focusing on the more critical problems including environmental sustainability. This program was organized by sector and what changes need to be made in each in order to move Chile towards sustainability (Larrain 2001).

One of the biggest environmental problems that needs to be addressed is the over-exploitation of natural resources. Mining has devastated many areas, and there are not funds to develop these areas. The native forests in Chile also are in decline. If the logging rate during 2001 continued, all native forests, besides those protected in national parks, would have been gone by 2011 (Larrain 2001). Another large environmental problem is pollution from the mining industry. All of the mining sites in Chile are considered saturated zones because of all the pollution they have caused (Larrain 2011). Some of these sites are being cleaned while others have been abandoned and people in the area have been relocated because it is unsafe to live there. The SCP proposed that the mining sector be better regulated, including raising their taxes to the same level as other industries. This will give the government extra funds for monitoring mining activities to make sure they follow environmental regulations. They also proposed a mining sales tax to help support communities that can no longer be mined. This can help rebuild them with new developments to support the local economy.

Societal Opinion

One of the biggest challenges to overcome in pursuing sustainable development is to get the backing of society. The ideas behind moving towards truly sustainable design will drastically change structures compared to what they are today. This type of change is often not welcomed by society unless they see an obvious necessity for it. Often times, people want solid proof of why things need to be changed. The need for sustainable design can be seen in the current global climate change and dwindling finite natural resources. Many people do not see these as large issues, especially because they are not having drastic negative effects that affect everyone on a day-to-day basis. A large part of sustainable design is to sustain the world for future generations. Some people do not recognize this, or do not see how the current situation can possibly have such negative effects for future generations.

Sustainability often carries the idea that "economic growth and material development can occur while, at the same time, social welfare, equity, and environmental conditions are maintained or improved" (Klepeis & Laris 2006). This can be a challenge to fully achieve in the current economic, social and environmental state. One big challenge is to increase communication in a way that is beneficial. Along with increased communication between stakeholders, cultural differences have to be overcome or put aside, and mutual trust must be built. This can be a significant challenge when green building groups are working internationally. The best methods for one country or even one town may not work in other countries because of cultural, climate, and economical differences. There are also large challenges faced by overcoming the goals of different interest groups. A challenge of sustainable development is to find a middle ground between environmentalists/preservationists and those pushing increased development and growth. Sustainable development tries to meet this challenge by developing methods to preserve natural resources and the environment. "To achieve sustainable development society needs to embrace humanized landscapes as places in which people can live and support themselves but also as places that maintain environmental services that provide personal fulfillment through interaction with nature" (Klepeis and Laris 2006).

A growing conclusion is that in order to achieve sustainable systems, fundamental nature-society relationships need to be reconsidered. These include the recognition that most areas on earth have been modified by humans, the definition of wilderness changes with culture and with time, the need to maintain environmental services, and realizing that parks need to be integrated into the development of the region (Klepeis and Laris 2006).

United States

A large obstacle in the sustainability movement is gaining societal approval. As an idea, sustainable building is typically widely approved of because of its reduction of negative impacts on the environment, as well as improved lighting, ventilation, and overall healthier living for its occupants. However, when it comes to actually creating and paying for sustainable buildings, many are reluctant. This is often because of perceptions higher costs and more complex design elements to achieve sustainable design. The added time and cost can seem much too substantive and not worth the benefits for many people. It is true that to achieve true sustainability, significant design changes have to be made, often with new innovative ideas to make a project work in a given location. However, ample research has been done to create sustainable technologies, as well as to make them more efficient and cost effective. Also, many sustainable projects have been successfully built around the world. This makes new sustainable projects much more feasible because of the vast knowledge already available for use.

The perceived added cost of building sustainably discourages many people. While the initial cost can be much higher for a sustainable project, much of this is usually offset in energy and water demands, as well as an increased lifespan. Studies have been done to examine the difference in costs for making a project LEED certified (Langdon 2007).

A study done by Davis Langdon in 2004 and revisited in 2007 analyzed the cost differences in LEED certified and non-LEED certified structures. This study used three methods to analyze sustainable building costs: the cost of individual sustainable elements, a comparison of LEED certified buildings to non-LEED certified buildings of the same use, and a comparison of initial project budgets to the price after being redesigned for LEED certification (Langdon 2007). They found that most projects could achieve LEED certification with little or no added cost. Many projects could achieve up to 12 LEED points without design changes, and 18 points with design changes adding little or no additional cost to the project (Langdon 2007).

The analysis of looking at the cost of added sustainable features showed varying costs depending on the LEED credit and the location of the project. In the materials and resources LEED section, all credits require extra documentation, which can add extra time and cost if not planned and done efficiently. The construction waste management and local materials credits depend greatly on the project location and its vicinity to material sources and waste and recycling centers. Credits in recycled content and rapidly renewable materials can be costly to achieve because of the high thresholds that must be reached to gain the credits. The certified wood credit varies in cost depending on project location, as well as the current supply and demand of wood. This analysis method is limited in that it does not look at how multiple LEED credits can be achieved with one added sustainable feature. It also does not look at how certain LEED credits can be obtained by changing a design element of the project instead of adding something on, which may reduce or not affect the overall cost of the project.

The second analysis compared 83 LEED certified projects with 138 non-LEED certified projects consisting of academic buildings, laboratories, libraries, community centers, and ambulatory care facilities. For each building type studied, there was no significant difference in cost between the LEED certified buildings and non-LEED certified buildings (Langdon 2007). This study is limited however, in that the cost per square foot for each building type varied greatly. This could have hidden significant cost differences from LEED certification.

Thirdly, initial project budgets before LEED design was incorporated were compared to the final project costs after LEED certification. This type of analysis is often used to assess the affordability of making a project LEED certified. The majority of the projects studied stayed in their initial budget when redesigned for LEED certification. A limitation of this study is that the initial budget may be inaccurate, significantly changing the cost difference between the non-LEED design and the final LEED certified project. Also, the initial project budget may have been set with the possibility of a sustainable design in mind.

This study showed that LEED certification could often be achieved with little or no added cost. Also, many of the projects studied strove for LEED points they could achieve with simpler, cheaper design changes instead of the more advanced or innovative sustainable features. They also found that many view sustainability as an added feature and added project cost instead of something that can be integrated in the original project design. Continued studies like this with a broader range of projects studied can help to change the perception to encourage people to build sustainably.

Chile

In Chile, there are disagreements between different groups about how the country's natural resources should be handled, including forests. One of these conflicts arose around a large logging project proposed in the Tierra del Fuego forest.

Rio Condor logging project in Tierra del Fuego

This project faced many challenges because of greatly differing views of different interest groups. Environmentalists were set against the logging project, and it became established as a nature reserve. They considered this a victory for sustainable development since it preserved some of the few remaining undisturbed forests in Chile (Klepeis and Laris 2006).

Some are questioning whether this action is truly a victory for sustainable development. People are increasingly shifting views from complete preservation to a middle ground where human well-being is balanced with a world rich in nature (Klepeis and Laris 2006).

Temperate forests in south-central Chile have been extensively logged and used for plantation forestry, farming, and ranching. They have also been diminished from invasive species, fire and agroindustrial pollution. The forests remaining in Chile are only 45 percent mature native forest due to high rates of plantation forestry (Kepleis and Laris 2006). On Chilean Tierra del Fuego, logging totaled over 20,000 m^3/year during the late 1990s.

A large part of the opposition for the Rio Condor project was due to the goals of the Trillium Corporation in charge of the logging. Their plan was to clear cut some virgin forests, which was against Chilean law. They had an environmental impact statement put together, but many groups did not trust the government to use this and enforce the environmental laws as they should be enforced. The project eventually lost funding and was partially turned into a nature reserve.

The distrust for those involved in the project was also caused by concerns about the science the project was based on. There were claims that the scale of the study was too small to have a detailed enough understanding of the soil conditions and growth rates. Those in charge of evaluating the project concluded that this project included a comprehensive program to conserve biodiversity at multiple levels and that it held a high degree of scientific credibility based on its scale and sophistication. This plan included creating almost 70,000 ha of ecological reserves, conserving habitats and structures by creating no harvest zones and rotating cuttings (Kepleis & Laris 2006). Even with these provisions to preserve parts of the forest, it still would have drastically changed the landscape, prompting many environmentalists to oppose the project.

This project is an example of a flawed decision-making process. Both the logging corporation and the environmentalists were not willing to compromise and collaborate in order to come to a good solution for what to do with the forest.

DISCUSSION

In order to achieve true sustainability, strict and highly sustainable programs, like the Living Building Challenge, need to be implemented. LEED and similar programs have made a widespread and significant impact in improving the sustainability of building projects and reducing their negative impact on the environment and the health of those living in it. However, these programs also somewhat limit sustainable design. Many projects will use the simplest and least expensive already developed technologies to reach the minimum required points to achieve the desired LEED certification level. The possible points for innovation in design will help counteract this for some projects, but not all of them. Many people are also under the perception that a LEED certified building is truly sustainable, instead of the reality that it is more sustainable than a conventionally designed building, but still needs much improvement to be truly sustainable. Programs like the LBC move towards truly sustainable structures. Although these types of projects are extremely limited in size and location because of their strict requirements, each project that is completed can set an example of what needs to be achieved and what can be achieved. Innovative design ideas and technologies used in these projects can be further developed for use on a larger scale.

The green building sector in Chile could benefit greatly from implementing small-scale projects at a higher level of sustainability. The development of these projects would also bring forward current limitations on sustainable building in the country in any or all of the main areas for sustainability including energy, materials, water, sustainable sites, and health. Some of these are seemingly impossible to improve. Others, once noted, can be improved upon in order to make true sustainability more achievable. For example, if there is a severe limit to certain renewable materials, work could be done to process more recycled materials, or to increase availability by planting more trees. Analyses could be performed to determine the areas that are most limited and the areas that could most easily and cost effectively be improved. This could then be worked into the overall budget.

CONCLUSION

The United States has implemented sustainable design in thousands of projects through certification programs like LEED and LBC. LEED especially has become very well known and easily attainable because many people in the industry are LEED accredited professionals or at least have experience working on LEED projects. The U.S. can improve sustainable development by continuing to promote and educate society about the need for sustainable design methods. While many LEED projects exist, future project should continue to pursue higher certification and a higher level of sustainability by implementing new technologies and design methods. In order to make truly sustainable design at all attainable, research must continue to find cost effective alternatives to conventional building practices including materials, construction methods, and building layout design. Promoting more projects that use the LBC program can motivate designers to work towards higher sustainability and give them ideas for how to achieve it.

While Chile is making large strides in sustainable development, there is always more that can be done to increase sustainability. Some more advanced ideas and methods currently used or researched in the United States can be applied in Chile to further their sustainable development.

Ways for Chile to further their sustainable development include:

- Using a program like the Living Building Challenge to create highly sustainable projects that can be models for improved sustainability.

- Increasing the use of recycled concrete aggregates in new concrete to cut down on the energy demand and GHG emissions from extracting, processing, and transporting natural aggregates.
- Using alternatives to portland cement in concrete to reduce GHG emissions and achieve desired concrete properties.
- Increasing certification and sustainable forestry management practices so wood can be utilized as a sustainable building material without destroying Chilean forests.
- Utilizing global research and successful sustainable design methods used throughout the world to create more sustainable structures.
- Performing life cycle analysis and life cycle cost estimates on sustainable and non-sustainable structures to see where sustainable design has significant benefits and where it can be made more efficient
- Continuing to promote the use and education of sustainable design and its importance in conserving and restoring the environment.

Implementing these methods in Chile could have large positive impacts in moving towards their goal of sustainable development. This could in turn be used in different countries in a similar fashion to continue global sustainable design.

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