Green Steel – Sustainable Steel Construction in the United States
A Sustainability Learning Module for an Introductory Design of Steel Structures Course
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Abstract

As human generated effects on the Earth’s atmosphere, ecology, biodiversity, and available natural resources are becoming more well-defined, the need has arisen to understand the effect of our actions on the world around us and shift our actions to have less detrimental impacts. Sustainable development is becoming a key focus in many classrooms across the country and structural design is no exception. As the focus increases on the environmental impact of buildings, attention is turning to the role that the structure plays in the building’s overall environmental performance. Steel has some inherently sustainable aspects as a material such as recyclability. There are also a number of strategies for designing and using steel that reduce natural resource use, construction waste, and environmental impacts. When designing for sustainability, LEED is the most prominent green building standard in use, but there are other methods not mentioned in LEED to achieve sustainable design as well. Other topics included in this document are suggested assignments for students and potential student resources for further learning.

Keywords

Steel Structures, Sustainability, Sustainable Development, Teaching Module

1. Class Material

1.1 Introduction – What is Sustainability?

In 1987, the Brundtland Report defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (UNCSD 2007). This definition was well-received and has been used by many other agencies, organizations, and governments.

The Brundtland definition for sustainable development makes no explicit mention of the environment. This is important, because sustainability can be about more than simply reducing negative environmental impacts. The often referenced aspects that can be considered during sustainable design are threefold: the environmental aspects of the design, the social aspects, and the economic aspects. These can be thought of as the “three P’s” or planet (environment), people (society), and profit (economy). This learning module focuses on the environmental aspect of sustainability.

As can be seen in Figure 1, the structure of a building accounts for a small amount of the buildings lifetime cumulative energy demand (maybe 5% of the total), and most of the energy impact from the structure takes place due to material manufacturing such as steel and cement.
production. If life cycle energy consumption is the only environmental impact considered, the design team might be misled into believing that the structure is relatively unimportant in sustainable design.

However, in the U.S. approximately 145 million tons of waste is produced annually from the construction industry (92% from demolition of the type shown in Figure 2). This is about one third of the solid waste in the U.S. (Kilbert 2008). Approximately six billion tons of materials are extracted from the earth each year to feed the needs of the construction industry which is approximately 40% of the total materials extracted in the U.S. Associated with the massive use of natural resources is the depletion of some basic metal stocks in the Earth. Approximately 26% of extractable copper and 19% of extractable zinc are already lost in nonrecycled human waste (Kilbert 2008).

![Figure 1. Cumulative Life Cycle Energy Components (AISC 2011)](image1)

![Figure 2. Picture of Building Demolition (from www.dallascontracting.com/demolition_contractor.html)](image2)

The sustainable development or green building movement has seen major successes in the United States and the world. The LEED program has had tremendous effect on the construction industry. It has effectively transformed the building industry in the minds of
developers, designers, builders, and users by attempting to set national standards and pushing for rapid implementation. Although there have been advances, there are still major challenges that remain. This learning module is intended to help students understand and think critically about the progress that has been made in the sustainability of steel construction and understand and evaluate possible solutions for the remaining challenges.

1.2 Sustainable Characteristics of Structural Steel

According to American Institute of Steel Construction (AISC), the representative of the structural steel industry in the United States, the recycled content of structural steel is 93.3%, which is the highest of any building framing material (AISC 2009). Other characteristics of structural steel (from AISC) are:
- Recycling rate of 98%
- High strength-to-weight ratio
- Steel can be recycled many times without any degradation in quality or strength
- The carbon footprint per ton of steel produced has been reduced by 47% since 1990
- The greenhouse gas emissions per ton of steel has been reduced by 45% since 1975

These characteristics all show that steel is an attractive building material for many reasons beyond its traditional features of cost efficiency and relative ease of design and construction. There are, however, other issues to consider. For example, the extraction of raw materials from the earth is an important consideration for any building material. In the case of steel, this is a diminishing concern due to the high recyclability of the material. As buildings are demolished, the structural steel can be reused over and over, with no reduction in strength. This is important because the production of virgin steel takes a significant toll on the environment, but the impact is much less when the steel is recycled. According to Sustainable Construction (Kibert 2008), producing one ton of recycled steel saves 2,500 pounds of iron ore, 1,400 pounds of coal, and 120 pounds of limestone.

Another issue is the amount of energy that is used to produce steel. According to the World Steel Association, in the United States the steel industry uses approximately 2% of all domestic energy each year (WSA 2010). Steel is typically produced using one of two methods: the integrated blast furnace (BF) or the electric arc furnace (EAF). The blast furnace uses mainly new materials to produce steel, while the electric arc furnace uses on average 96% recycled material (Kilbert 2008). The EAF uses less fuel onsite and has a much higher recycled content (the recycled content of the BF is approximately 32%) but requires a large amount of electricity and needs a connection to a reliable electric grid. Innovative improvements to the EAF process have been researched and implemented in Europe to further reduce energy demands by using old tires in the furnace to offset coke requirements (Sahajwalla et al. 2009 and WAS 2010).

There are major benefits to including a higher percentage of recycled steel in the EAF process besides the reclamation of used steel. The EAF process using recycled steel requires approximately 20% of the energy as the same process using non-recycled steel (Kilbert 2008). In the United States and other developed countries, steel recycling is well-established and has been developed to the point where using recycled steel is more economical than using virgin materials to produce new steel.
The construction phase of buildings is important in terms of energy, material use and material waste. The construction and operation of buildings consume 40% of the world’s total energy (although the majority is during the operation phase) and the construction industry is responsible for 40% of the world’s flow of raw materials on a yearly basis (Burgan and Sansom, 2006) For steel, however, the most intense energy use occurs during production rather than construction. Furthermore, steel with a higher recycled content requires less energy to produce. Construction waste is also an important factor when considering sustainable design. In the United States alone approximately 140 million tons of construction and demolition waste are produced each year. This represents one third of the solid waste generated in the US (Kilbert 2008). In the European Union (EU) 72% of construction waste is sent to a landfill (Burgan and Sansom, 2006). It is important to note that a small reduction in the waste generated in the construction industry can lead to a large reduction in the overall solid waste stream. The recyclability of structural steel is a significant component in reducing construction waste. A properly designed, maintained, and demolished structure can have up to 100% of its steel recycled and reused.

A key tool used by many sustainable design practitioners is called life cycle assessment (LCA). A life cycle assessment can be performed for virtually anything, including a product, a process, or an industry. A properly performed life cycle assessment will consider many different environmental impacts, such as ozone depletion, global warming, eutrophication, air pollution, and more. A LCA can also consider all phases (or a partial segment of the life cycle if desired) of the product or process: extraction, production, use, and disposal/recycling. For example, in the case of structural steel that is made from raw materials, a LCA might first investigate the environmental impacts due to the resources, energy, etc. that are needed to extract the raw materials from the earth. Then it would consider the environmental impacts that occur during the production of the steel. Next it would look at the impacts occurring during the use of the structural steel (i.e. the construction and maintenance of the building). Finally, it would consider any impacts due to the disposal or recycling of the steel. If the steel is sent to a landfill, then consideration is given to the land used for the landfill, possible leaks in the landfill lining, etc.

Performing an LCA can be helpful because environmental impacts can be traced back to specific decisions. Steel shapes are manufactured at the steel mill which may be either BF or
EAF. The shapes are then transported to warehouses called service centers located throughout the country that then distribute the steel to local fabricators. The fabricator will prepare the pieces for construction and send them to the job site. The chain of manufacture and delivery can be complex. LCA can help a design team make environmentally smart decisions about where to obtain steel to minimize the environmental impacts.

It should be noted that there are several useful LCA computer programs available, such as the Athena Software, Building for Environmental and Economic Sustainability (BEES) and SimaPRO. The available programs contain environmental data on most common materials and can save the practitioner much time by providing it in an easy to use and convenient manner.

1.3 LEED

Leadership in Energy and Environmental Design (LEED) has quickly become the standard for sustainable design in the United States and serves as a template for sustainable codes in other parts of the world. LEED is published by the United States Green Building Council (USGBC), which was founded in 1993 (Danatzko, 2010). A building following LEED guidelines can be certified as silver, gold, or platinum. This is attractive to all parties involved, as a LEED certification serves as a proxy for environmental friendliness and studies have shown that LEED certified buildings fetch higher prices in the market-place. This demonstrates that users are willing to pay a higher price for what they deem to be sustainable features in a building.

The LEED rating system awards points to a project out of 100 possible total points. To achieve certified status 40-49 points are required. Silver requires 50-59 points, gold requires 60-79, and platinum requires 80 or more (USGBC 2012). To be certified platinum, a great amount of effort is required by the owner and design teams and it is something that must be actively and diligently pursued.

There are several ways that structural steel can be used to help achieve the goal of LEED certification. The most obvious of these ways are under the Materials and Resources (MR) category of the LEED rating system, which accounts for up to 14 possible points in the LEED 2009 system (USGBC 2012). Danatzko (2010) outlines the specific credits that can be associated with the structural system and how the points can be achieved. For example, Credit 1.1 in the Materials and Resources category is related to the reusing and maintaining existing parts of the structure. This falls into the realm of the structural engineer. If 55% or more of the building is reused, 1 point is awarded. The credit awards 2 points for 75% reuse and 3 points for 95% reuse.

MR Credit 3 concerns material reuse. The structural engineer, for example, can reuse certain steel sections if they are deemed to be in acceptable condition and are relatively easy to disassemble and salvage (this is made easier if the building frame was designed for disassembly, a concept addressed later). An interesting example of using reclaimed natural gas piping for structural columns is provided in Guggemos and Franklin (2011). Up to 2 points can be earned under this credit.

MR Credit 4 awards up to 2 points for the recycled content used in the project. The intent is to reduce demand for virgin materials which put a strain on the environment during extraction and processing. If the project uses 10% recycled content, 1 point is awarded. If 20% recycled content is utilized, 2 points will be awarded. Steel can play a significant role in achieving these points because structural steel produced by an electric arc furnace contains on average 96% recycled content.
MR Credit 5 awards up to 2 points to projects that utilize regional materials. The credit awards 1 point for at least 10% regional materials and 2 points for 20% or more regional material use. To qualify as being a regional material, the material must have been extracted, harvested, and manufactured within a 500 mile radius of the project site.

An interesting case study is provided in Modern Steel Constriction of a LEED certified building (Allen 2008). In this article the author describes a steel-framed DMV building in California that successfully obtains LEED gold certification. The building contains innovative design features that increase its sustainability. For example, it has 30 in. deep girders that cantilever out from the roof of the building to form a 45 ft overhang, providing shade for waiting DMV-goers, which encourages them to make use of the outdoor space. Another feature, although not related to steel, is the use of masonry walls as lateral force resisting elements. The walls serve more than one purpose—they resist the potential ground shaking in the seismically active region as well as serving as thermal masses to decrease the energy use of the building. The selection of steel as the framing material was partly motivated by its ability to provide open walls with large amounts of space for windows. Through the innovative use of windows and skylights, natural daylight is provided in 89% of occupied spaces in the building. Additionally, during construction the contractor recycled 60% of the waste.

1.4 Beyond LEED – Alternative Ways to Achieve Sustainable Design

LEED is certainly a good starting point, and for many designers it is an end in itself. There are, however, other ways to achieve a sustainable design either by going above and beyond LEED or by using an alternative sustainable design standard or method. For example, although LEED awards points for achieving a certain percentage of regional materials, it may be worth it for the designer to avoid specifying any type of steel that is only available from foreign sources. This is due to the differences in environmental policies and state of the steel industry in other countries. For example, China produced one third of the world’s steel supply in 2008 but emitted 50% of the steel industry’s total carbon dioxide emissions (Lorenz and Vangeem, 2011). The inefficiencies that cause the steel mills in China to use more energy and emit more pollutants are due to smaller plants that use out-dated technology (Guo and Fu 2010). Steel from other countries can sometimes be more economical, but the designer should be aware of the differences in embodied energy and carbon dioxide emissions.

One sustainable design method that is gaining in popularity is design for deconstruction or design for disassembly (DfD, either way). Deconstruction is the disassembly of all or parts of a building so that the parts can be reused elsewhere (Kilbert 2008). To be most effective, the reused parts would be utilized onsite for the new building. Lorenz and Vangeem (2011) lay out several strategies that can be used to effectively design for deconstruction, such as using prefabricated components, simplifying connections, separating building systems (mechanical, electrical, etc.), keeping the different types of building materials to a minimum, using quickly disassembled connections, using reusable materials, and designing the building for flexibility in use. One key here is the point on connection design. Although it is common for structural engineers to use shop-welded and field-bolted connections, there are of course many instances when the engineer desires to have field-welded connections as well. Using the logic of DfD, the engineer should detail as many bolted connections as possible, as these are easier and faster to disassemble, leading to an increased probability of reuse at the end-of-life of the building.
Reusing structural steel members from an old building can pose concerns for some structural engineers that can be addressed through proper DfD. Lack of information regarding things such as materials, loading during its life span, and potential risk related to possibly contaminated materials such as fire-proofing may make future structural engineers wary of reusing the deconstructed members (Lorenz and Vangeem, 2011). To alleviate some of these concerns, a good strategy might be to create a deconstruction plan, which would specify steel materials used, design loads, capacities that are acceptable during the deconstruction phase, as well as a sequence to be followed to deconstruct the building. The Structural Engineering Institute (SEI) recommends that all steel members be labeled clearly so that it is easy to determine their exact nature during deconstruction. It also recommends that as-built plans be stored in a safe place so that future designers and owners know the actual features of the building, thus facilitating changes to the building’s use in order to extend its life.

There are other strategies for DfD that clash with current structural design practices. For example, to be able to quickly deconstruct a building it makes sense that the designer should avoid mixing materials together which are difficult to separate (i.e. composite materials) (Kilbert 2008). However, composite materials are central to structural engineering—from reinforced concrete to composite steel decks. The designer must find a way to increase sustainability while at the same time maintaining the strength, integrity, and efficiency of the building.

An interesting example of designing for deconstruction is provided in the January 2011 issue of Modern Steel Construction (Koklanos, 2011). The article explains the story of the new souvenir shop on Liberty Island, home of the Statue of Liberty, which replaced the old gift shop housed in a tent. The US National Park Service required that the building be LEED gold certified, and granted only a 10-year lease to the owners. This meant that the building needed to be designed for deconstruction, in case the owners’ lease was not renewed. The structural engineers for the building used all field-bolted connections, with all required welding done in the shop. This led to a quicker construction and inspection, as well as a design that is easily deconstructed at the end of the 10 year lease. The engineers utilized a design that minimized unusual conditions and cut down on the overall numbers of connections. An additional sustainable feature of the building is hot-dip galvanized steel members which serve to increase durability when exposed to weather. The structural steel members are composed of more than 99% recycled content. A key to the success of the building was that the structural engineering and sustainability consulting were part of the same company, leading to an unusual but productive level of collaboration.
Other design approaches for sustainability in structural steel include design for adaptability, design for construction speed, and design for least materials. *Design for adaptability* (DfA) is an effort by the design professionals to accommodate future unplanned building uses. For example, an apartment building might be converted into a school—or vice versa. DfA requires some of the same strategies as DfD, such as structural simplicity and repetition. Structural simplicity makes it more likely that a future engineer will be willing to reuse or adapt the structural system for a different building use. Strategies for DfA include: designing for live loads higher than the code minimums; using redundant and resilient structural members, which provides future tenants or owners with the ability to alter the structural system if needed (for example, to add doors in shearwalls); sizing the gravity members for potential future vertical additions; coordinating with building system (mechanical, electrical, etc.) to make any future renovations easier (Kestner and Webster, 2010).

*Design for construction speed* improves both the economy and sustainability of a building. It decreases labor costs as well as several adverse environmental effects. These include CO$_2$ emissions that are associated with the running of a construction project (equipment, generators, etc.) and the erosion and runoff problems connected to the disturbance of a site during construction. *Design for least materials* can also improve the economy and sustainability of a building. Designing for the use of the least amount of steel is desirable because it saves money as well as steel, thus reducing the environmental effects of the steel. An efficient, lightweight structural design has always been a goal of the structural engineer, but caution should be used here because highly efficient designs can sometimes be accompanied by increased
construction time, more complicated detailing requirements, and a higher rate of construction mistakes. It is possible that these negative factors could offset gains made in terms of cost and environment.

1.5 Where do we go from here?

A valid question for sustainable steel construction is *what happens now?* What’s next? AISC provides some guidance as to what the future of sustainable structural steel may include. First, as the general electrical supply in the United States becomes more renewable (an increased reliance on wind, solar, etc.) structural steel will become more sustainable due to a decreased level of embodied carbon. This is true, due to the high levels of energy used in the production of steel with the electric arc furnace. It should be noted, however, that many building materials will benefit from a more renewable power supply. The second point that AISC makes is that research is ongoing to establish a new production process that can produce carbon-neutral steel. Thirdly, AISC points to the combined power of the steel industry, which is working as a team to address sustainability problems on a global scale (AISC 2009).

A logical progression would be to continue the sustainable education of new engineers. It is important that the future professionals understand the need and techniques for sustainable design, including the key concepts and theory behind conducting a life cycle assessment of structural steel and an overall building. Professionals can become advocates for structural design by helping owners, architects, and users understand its place and significance in the life of a building. Further research and refinement of green building codes, standards, and rating systems, such as LEED, is ongoing. A new LEED standard will be released in 2013 with major input from interested parties. As LEED becomes more widespread and accepted, the public is becoming more aware of sustainable attributes of buildings and is willing to pay continually higher premiums for green designs, to the point where certain sustainable aspects are becoming standard in new buildings, such as high recycled content.

1.6 Conclusions

Structural steel has the characteristics of a sustainable building material, with its high rate of recycled content, regional production and transportation, potential for minimal framing sizes (leading to larger window and skylight openings), and more. It also presents some challenges to sustainability, including high embodied energy content and requirements for maintenance, painting, and fireproofing. Overall, the building material is suitable for future green building designs, due to its environmentally friendly properties, widespread use and acceptance, and the large body of knowledge on its structural properties and familiarity to structural engineers.

As our understanding of man-made changes to the environment develop and the focus on sustainable construction increases, it is important that students learn of the related sustainability issues, tools to assess sustainability, and possible solutions for reducing environmental impacts. Sustainability criteria should be emphasized as important design considerations, although it should be placed in the context that environmental impacts are only one of the three P’s that are significant design considerations (People, Planet, and Profit). Sustainable design techniques should be incorporated into every phase of the building’s life, from the conceptual design through the construction, operation, and finally deconstruction, reuse, or recycling of a building.

2. Suggested Assignments for Students
Pre-lecture reading: A pre-lecture reading can be an important tool, as material can be learned by students that the professor would otherwise not have time to cover. It can also help prime the students for the lecture, saving the professor time. The reading assignment selection is left up to the professor (see references at the end of this document), but an example would be to have the students watch the National Environmental Report (a nine minute documentary provided by AISC) and then read two of the case studies under “Green Steel Projects.” These are available at AISC’s website, http://www.aisc.org/content.aspx?id=17560. Note that this link is also available in section 1.8 Potential References for Students. The professor may wish to assign a one page discussion paper with several questions to be answered by the students to ensure the completion of the readings.

Post-lecture assignment: Several possible assignments are available below for completion by the students after the sustainable design lecture. The goal of the assignments is for the students to synthesize the information they have learned in the readings and during the lecture.

1. Research a sustainability topic related to steel and write a short paper summarizing your findings (2 pages). Examples of potential topics include electric arc furnaces versus blast furnaces, design for disassembly, comparisons of environmental impacts of steel buildings to concrete buildings, LCA as a design tool, etc. The paper should include at least three references.

2. Identify a local building that has achieved LEED Silver certification or better and find out what aspects of the design led to this certification. The students should contact the structural engineer or architect for the project and conduct a short interview about the building. Some possible suggestions for questions include the following:
   a. What LEED points were achieved related to the structure?
   b. What had to be done to achieve those points (any unusual specifications for instance)?
   c. Anything unusual or interesting about this project or the design process?
   d. Do people at your company have LEED accreditation? Do you think LEED accreditation is important?
   e. How involved was the structural engineer in the LEED process?
   f. What percentage of your projects have LEED certification?

Write a short (2 page) memo to the professor about your interview.

3. Split into groups of 3 or 4 students. Create a simple model green building code for structural steel design (1 page). Write the green building code in the form of a numbered list of requirements organized into categories based on phase of construction (such as manufacturing, distribution, design, fabrication, erection, disassembly, recycling) in specification language (using phrases like “shall be”, “shall have”, “it is permissible to”, “are permitted”). Write a commentary to the green building code (2 pages) that describes the intent of each specification.

4. Split into groups of 3 students. Each group will have a proponent for the steel industry, concrete industry and timber industry. Each team member will write one page supporting
why their material is a more sustainable material than the other two. Each team member must use at least three references. The group as a whole must write together an introduction and conclusion (totaling one additional page), that summarizes the difficulties in comparing building materials and any possible conclusions that can be made. As demonstrated in the literature, there is not a consensus on the topic of whether one construction material is better for the environment than another, but there is a plethora of available research.

5. Select a case study (some are available at the AISC link in the pre-lecture reading section) and present the key details of this project to the class. Due to the limited number of case studies in the literature, the students should be split into groups such that each group can investigate a unique case study. The presentations should be 10 minutes (this can vary based on availability of class time), be well organized and at a minimum should include the following:
   a. Introduction clearly identifying the case study project
   b. Tell the location of the project, and identify all the key parties (owner, architect, structural engineer, fabricator if available, etc).
   c. Give an overview of the purpose of the building, general layout of the building
   d. Identify each of the characteristics of the building that reduce environmental impacts relative to typical construction
   e. Summary of how the design decisions led affected the environmental impacts for this building.
Criteria for grading of the presentation should reflect whether the minimum content was included, but can also be used to improve student presentation skills. Criteria such as format and presentation of material on slides as well as presentation skills such as minimizing nervous gestures, speaking loudly and clearly, and looking at the audience are encouraged.

6. Conduct a field trip to a local LEED certified building under construction. In most cities and towns (especially those that include university campuses) there is often at least one LEED certified building under construction. If possible, the instructor is encouraged to engage the architect and attempt to have a representative from the architect present to discuss the sustainable features of the project. The students would then write a 2 page memo to the professor identifying specific issues related the sustainability / environmental impacts of the building that they learned about on the field trip.

3. Suggested References for Students to Review
The Design for Sustainability section provided by AISC contains valuable sustainable design information. It can be found at http://www.aisc.org/content.aspx?id=17560 and contains many examples of “Green Steel Projects” and information relating to LEED and steel design.
Another useful resource is the LEED section of the USGBC website (https://new.usgbc.org/leed). This includes an introduction to LEED and information relating to the rating system, certification tools and guides, and professional accreditation information.
Of interest to many students and professionals alike is Modern Steel Construction. Every issue is available online and in many of the recent years the issues contain sustainability related articles. The archives can be found at http://www.modernsteel.com/archives.php.

Two interesting articles appear in the magazine Canadian Architect concerning the sustainability of steel. They were found through Virginia Tech’s library and are likely available through many other systems. The citations for the article are below (there are two authors for the articles, each named S. Boulanger).


A paper appearing in the journal Frontiers of Architecture and Civil Engineering in China by three Italian engineers provides an excellent source of peer-reviewed information on the sustainability of steel buildings. It contains an overview of the environmental issues at hand as well as the basic ideas behind designing a building for sustainability. The paper is about eight pages long and could potentially be used as part of a reading and discussion assignment. The citation for the article appears below and can be found in a university library system.


Other possible resources for students can be found in the reference list below, which contains websites, journal articles, etc. with further information relating to the topics addressed in this paper.

4. References


