

LEED-NC version 2.2 rating system applications of common structural materials

J.E. Maher

Opus Architects & Engineers, Minnetonka, MN, USA

K.W. Kramer

Department of Architectural Engineering and Construction Science, Kansas State University, Manhattan, KS, USA

ABSTRACT: Comprehensive understanding of building materials has been the basis of structural engineering. The rising environmental concern is making sustainability a crucial issue in our society. In creating a sustainable built environment, the architect usually takes the lead role with the mechanical engineer having the key responsibility for energy and water savings. Only recently have structural engineers and civil engineers begun to see the real potential of their contributions. This paper contains information pertaining to the four most common structural materials: reinforced concrete, reinforced masonry, steel, and timber. For each material, the sustainability of the material as defined by the LEED-NC Version 2.2 rating system is discussed. Information is provided on how to attain LEED points for a specific material. Whether the LEED-NC Version 2.2 rating system accurately portrays sustainability of common structural materials or needs further development is discussed in the conclusion. A comparison is provided of the four common structural materials in relation to the rating system.

1 INTRODUCTION

Edmund Burke once wrote, “Society is a partnership, not only between those who are living, but between those who are living, those who are dead, and those who are to be born” [Burke 1790]. This statement exemplifies the importance of sustainability, and why it is imperative to consider sustainability in all aspects of design and construction. Implementation of sustainability practices in the built environment is a trend that will continue as owners, along with the building and construction industries, are exposed to society’s increasing concern about the environment. Though involvement in sustainability is voluntary for some, the entire building industry is realizing its importance, as new standards are set. As of April 2005, 46 county, city, and state governments have adopted policies requiring or promoting the use of sustainability with the goal of encouraging environmentally sensitive and responsible design to create healthy communities [USGBC 2006].

Leadership in Energy and Environmental Design (LEED) was formed by the United States Green Building Council (USGBC) to address this concern. LEED created a rating system entitled LEED for New Construction and Major Renovation Projects, otherwise referred to as the LEED-NC Version 2.2 rating

system which provides a comprehensive framework to assess the overall building performance and a points system for achieving certification levels.

Architects, along with mechanical engineers, are given the lead role in application of the LEED-NC rating system to the built environment. Structural engineers have had an obligation for the well-being of current and future generations, but until recently their importance in achieving sustainable design was not realized. Knowledge of the structural materials, coordination of structural systems with mechanical systems, and comprehension of alternative structural systems is essential for structural engineers. This information assists in creating innovative sustainable solutions, an integrated design, and aid in application of the LEED-NC Version 2.2 rating system. The sustainability phenomenon continues to grow necessitating the need for structural engineers to be able to fully assess common structural materials and their benefits in sustainable design.

This paper discusses how the structural engineer can achieve this. Information is provided on why the LEED-NC Version 2.2 rating system is utilized to gauge sustainability along with an explanation of how the system assesses the built environment. The focus of the paper pertains to the four most common structural

materials: reinforced concrete, reinforced masonry, steel, and wood. For each one, the relevancy to LEED-NC is explained.

2 IMPORTANCE OF SUSTAINABILITY

Comprehension of sustainable design is necessary before one can examine sustainability of structural materials. The World Commission on Environment and Development (WCED) defines sustainability as “meeting the needs of the present without compromising the needs of the future.” Sustainability is a word that encompasses many terms. Green design, green buildings, green engineering, green design, sustainable buildings, green architecture, ecological design, eco-effective, holistic, and environmentally friendly design are just some of the names used to refer to the issues of sustainability of structural materials. All of which encompass a similar meaning [McLennan 2004]. For the purpose of this paper, sustainable design will be used.

Sustainable design has many benefits. Considering the environmental impact, the obvious contribution is the ability to enhance and protect ecosystems and biodiversity by limiting the building’s environmental footprint. Building’s environmental footprint is the building’s use of public utilities and the waste put back into the environment. Some environmental benefits are improvement in air and water quality, reduction in solid wastes, and natural resources conserved. Economic benefits include reduced building operating costs, enhancements of the asset value and profits by improved employee satisfaction and efficiency, and optimized life-cycle economic performance. Additionally, tax credits and other incentives provided by the government are becoming common to promote sustainable design.

Benefits to people include improved air quality, increased thermal comfort, better acoustical environments, enhanced well-being and comfort of the occupant, and overall improvement in the quality of life

2.1 *The role of the construction and building industry*

The functionality, aesthetics, healthfulness, safety, environmental quality, and economy of buildings are vital to the quality of life and productivity of the individuals who use these buildings. In the United States (U.S.) in 2002, new construction and renovation of buildings accounted for about 9% of the Gross Domestic Product; the value of existing buildings comprised about 48% of the fixed, reproducible, tangible wealth; buildings consume about 40% of the energy; and construction wastes were estimated to be 20–30% of the contents of landfills [U.S. Bureau of the Census 2002]. In addition,

buildings account for 36% of the total energy use, 65% of the electricity consumption, 30% of greenhouse gas emissions, 30% of raw materials use, 30% of waste output (136 million tons annually), and 12% of potable water consumption [USGBC 2005b].

Clearly, there are areas of opportunity that sustainable design can address. Engineers can play a significant role in planning, designing, building and maintaining the environment. Engineers must participate with owners, suppliers, investors, regulators, community interest groups, ecologists, sociologists, and professionals from other disciplines in order to achieve sustainable strategies and solutions. Engineers provide the bridge between science and society. For example, by addressing an element in the code of Ethics of the American Society of Civil Engineers (ASCE), the engineer has a responsibility to support sustainability that requires civil engineers to strive to comply with the principles of sustainable development in the performance of their professional duties [Vanegas 2004].

Fortunately, breakthroughs in building science, technology, and operations are available to assist in advancing sustainability. Designers, builders, and owners have the ability to maximize both economic and environmental performance for the inhabitants while preserving the environment [USGBC 2005b]. Achievement of sustainability requires engineering expertise. Structural engineers can contribute to sustainability in many ways:

- Comparing embodied energy of various construction materials and systems.
- Coordinating structural systems with mechanical engineers to enhance the efficiency of Heating, Ventilation, and Air Conditioning (HVAC) systems.
- Teaming with building officials to allow both alternative materials and systems.
- Working with wind-tunnel studies of double-skin facades to create naturally ventilated buildings [Field & Hun 2006].

Structural engineers have the duty to lessen the environmental impact by using their comprehensive understanding of building materials to create integrated sustainable designs.

3 ASSESSING SUSTAINABLE DESIGN

In response to the rising concern for the environment and sustainability of the U.S., two primary approaches have emerged to gauge the environmental friendliness of a building. One approach is Life-Cycle Analysis/Assessment (LCA) which emerged in the early 1970s. The second approach is Leadership in Energy and Environmental Design (LEED).

LCA has several interchangeable terms; these include life cycle inventory, cradle-to-grave analysis,

product life-cycle analysis, environmental profile analysis, and eco-balance. These terms all mean “measuring the total impact of a product on the environment – from when the raw materials are extracted, through the product’s life as a consumer item, to when it is disposed of or recycled” [FWPRDC 2006]. This method is much more elaborate than LEED rating system, because it involves extensive computation and documentation of data (i.e. embodied energy, life cycle cost) not readily assessable and can be challenging to accurately develop [Hewitt 2003]. Unlike the LEED system, LCA has multiple methods to rate a building varying in complexity.

In using LCA, results are often based on inadequate and incomplete data because of a lack of documentation and unavoidable assumptions about product life resulting from a lack of scientific basis [FWPRDC 2006]. Subjective questions arise, such as; how should heavy water use be compared to heavy energy demand; how should the combined impacts of landfilling of wastes be compared to pollution; and how should wastes created from burning be compared to energy production, etc. Unavoidably, the LCA approach entails subjective decisions in determining the significance of differing qualitative values [GDRC 2006]. Often, LCAs arrive at different and conflicting results. Even with similar products, assumptions are necessary. “For example, whether deliveries were made in an 8.2 ton (9 U.S. tons) truck, or a larger one, whether it used diesel or petrol (gasoline), and ran on congested city roads where fuel efficiencies are lower, or on country roads or motorways where fuel efficiencies might be better. Comparisons of products which are dissimilar in most respects can only be made by making even more judgments and assumptions” [GDRC 2006]. A further aspect to consider is obtaining accurate data while maintaining the confidentiality of commercially-sensitive data. Companies are understandably reluctant to publish information, which may indicate inferiority to competitors [GDRC 2006]. Currently, LCA is not developed enough to merit comparison of structural materials. “The system’s precision and usefulness as a comparative tool give it potential for future use, but the difficulties in obtaining accurate energy information could preclude the method’s use for some time” [Hewitt 2003].

The second approach, LEED, was developed by the United States Green Building Council (USGBC). The USGBC was formed in 1993 as “the nation’s foremost coalition of leaders from across the building industry working to promote buildings that are environmentally responsible, profitable and healthy places to live and work” [USGBC 2005a]. USGBC represents the largest breadth of membership in the entire green building industry, thereby creating a strong and diverse organization. Unique perspectives combined with collective power give members the

opportunity to “effect change in the way buildings are designed, built and maintained” [USGBC 2005a]. The council works together developing, managing, and forging alliances by various means to increase the support for sustainable building design. With this purpose in mind, the USGBC created 28 committees to focus on different programs of concern. “Council programs are committee-based, member-driven, and consensus-focused” [USGBC 2005a]. To remain consensus-focused, the USGBC employs decision-making that encompasses a diverse membership. “The Council’s policy for balloting LEED products helps assure that all membership comments are considered and that final decisions and rationales are conveyed to the membership prior to final votes” Moreover, whereas consensus typically means that a simple majority of those voting approves a given issue, Council policies require a two-thirds approval of those voting for a standard to be approved” [USGBC 2005a]. Based upon these ideals, the council members established LEED. Though neither LEED nor LCA are flawless in any context, LEED is currently the more accepted approach in the United States, because LEED is less complicated and more encompassing in comparison to the LCA.

3.1 *Leadership in Energy and Environmental Design (LEED)*

As previously stated, USGBC members from all segments of the building industry collaborated to continually develop LEED. LEED’s mission statement is: LEED encourages and accelerates global adoption of sustainable green building and development practices through the creation and implementation of universally understood and accepted standards, tools and performance criteria [LEED 2005].

The evolution of LEED was based on promoting integrated building design practices and raising consumer awareness of the benefits of building green while in the process generate a consensus-based standard for evolving sustainable buildings. The objective is that LEED standards would stimulate a transformation of the building market towards “green” competition and in turn LEED would recognize sustainable leadership in the building sector. Currently, LEED has six standards. The forefather standard, originally published in 1999 and now on edition three (LEED-NC Version 2.2), and the most commonly used in the green building industry is New Commercial Construction and Major Renovation Projects (LEED-NC). LEED-NC provides a comprehensive framework to assist in meeting the sustainability standards and assessing the overall building performance.

3.1.1 *LEED-NC Version 2.2 rating system*

LEED-NC is a sustainable building rating system designed to guide and distinguish high-performance

Table 1. LEED-NC certification levels.

Level	Points Required ¹
Certified	26–32
Silver	33–38
Gold	39–51
Platinum	52–69

¹ 69 Possible Points.

Table 2. LEED-NC rating system.

Category	Prereqs	Credits ¹	Points
Sustainable sites	1	14	14
Water efficiency	–	5	5
Energy & Atmosphere	3	6	17
Materials & Resources	1	13	13
Indoor environmental Quality	2	15	15
Innovation & Design Process	–	5	5

¹ Includes sub-credits.

commercial and institutional projects, with an original focus on office buildings which has evolved to K-12 schools, multi-unit residential buildings, manufacturing plants, laboratories and many other building types. [LEED 2005]. LEED-NC Version 2.2 is the current document used for new construction and major renovations projects designed to achieve LEED certification. The four certification levels, shown in Table 1, are used to recognize achievements for building green.

LEED-NC is divided into five main categories concerned with the quality of sustainability accounting for 64 of the 69 points possible. The prerequisites must be met first in all the categories before a project can obtain any credits. Once the prerequisites have been satisfied, a project must obtain a certain number of credits to achieve the desired level of certification. The other 5 points are earned through innovation and the use of a LEED-accredited professional on the project. To aid with this process the LEED-NC Version 2.2 manual has intents, requirements, potential technologies, and strategies for acquiring each credit. Refer to Table 2 for a summarization of the categories, credits, and points possible.

The categories in the LEED-NC rating system that pertain to the sustainability of structural materials are Sustainable Sites, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation & Design Process. A detailed explanation of each category is available in the LEED Reference Guide. A brief description of these categories is as follows:

- Sustainable Sites: Consideration in site selection to preserve or restore the local ecosystem. Site selection

also has the ability to impact credits that may not seem directly associated with the site. For instance, a site near public transportation or in a previously developed area reduces the amount of driving by the building's occupants.

- Energy & Atmosphere: To help reduce energy use and protect the ozone layer by minimizing the amount of energy necessary and optimize the energy performance of the structure.
- Materials & Resources: To conserve raw materials and resources, for example fossil fuels. Techniques include increasing recycling and recycled content, redirecting material from landfills, and decreasing travel distances for material and product transport.
- Indoor Environmental Quality: Due to Americans spending 90% of their time inside, the indoor environment has a crucial affect on health and productivity. Related concerns encompass occupant comfort, quality of the air, thermal comfort, and daylight access.
- Innovation & Design Process: The USGBC acknowledges that LEED is a relatively new system – possibility exists that not all sustainable building aspects are covered. This category recognizes innovative solutions and having a LEED accredited professional on the project [Stern et al. 2003].

4 LEED-NC AND STRUCTURAL MATERIALS

The categories that pertain, directly or indirectly, to the four structural materials covered in this paper are Sustainable Sites, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation & Design Process. The following sections will explain the applicable credits based upon information obtained in the LEED-NC Version 2.2 Reference Manual. Correlations of these credits to the common structural materials will be made in order to understand the building's environmental footprint. The pertinent credits are summarized in Table 3 located in the Appendix.

4.1 Sustainable Sites

The first category listed in Table 3 in Sustainable Sites. Destruction to local ecology is often caused by development and construction processes. Within Sustainable Sites credits 3, 5.1, 5.2, 6.1, and 7.1 apply to structural material sustainability.

4.1.1 Sustainable sites, credit 3, brownfield redevelopment

The intent of this credit is to rehabilitate sites damaged by environmental contamination thereby reducing demands on greenfield sites. To achieve this credit, one must develop on contaminated land or land

classified as a brownfield site. Documentation is mandatory indicating either site contamination or a brownfield site and the remediation implemented. In these areas, cement can be utilized to stabilize and solidify contaminated soils while reducing leachate concentrations to acceptable levels. As indicated in Table 4 located in the Appendix of the four common materials reviewed, concrete is the only structural material which can obtain this credit which is worth 1 point.

4.1.2 *Sustainable sites, credit 5.1, site development – protect or restore habitat*

The intent of this credits to provide habitat and promote biodiversity by preserving existing natural areas and restoring damaged regions. This credit can be obtained by two options. The requirements vary based on whether the site is a greenfield or brownfield site. Option 1 pertains to greenfield sites as follows, “On greenfield sites, limit all site disturbance to 12 m (40 feet) beyond the building perimeter; 3 m (10 feet) beyond surface walkways, patios, surface parking and utilities less than 300 mm (12 inches) in diameter; 4.5 m (15 feet) beyond primary roadway curbs and main utility branch trenches; and 7.5 m (25 feet) beyond constructed areas with permeable surfaces (such as pervious paving areas, stormwater detention facilities and playing fields) that require additional staging areas in order to limit compaction in the constructed area” [LEED-NC 2005].

Option 2 pertains to previously developed sites, often a brownfield site and is further defined as, “On previously developed or graded sites, restore or protect a minimum of 50% of the site area (excluding the building footprint) with native or adapted vegetation. Native/adapted plants are plants indigenous to a locality or cultivars of native plants that are adapted to the local climate and are not considered invasive species or noxious weeds. Projects earning SS Credit 2 and using vegetated roof surfaces may apply the vegetated roof surface to this calculation if the plants meet the definition of native/adapted” [LEED-NC 2005].

Since surface parking tends to have large impact on the site, providing a parking garage will reduce this impact. Parking structures typically constructed on reinforced concrete on the lower levels of reinforced concrete, reinforced masonry, steel, and wood structures can be utilized to achieve this credit. Three of common structural materials, reinforced concrete, reinforced masonry or steel can be utilized to support vegetated roof surfaces. Either option creates limited site disturbance thereby sustaining vegetation. This credit is worth 1 point.

4.1.3 *Sustainable sites, credit 5.2, site development – maximize open space*

The intent of this credit is to support biodiversity by providing a high proportion of open space to developed

area. This credit is achieved by meeting the requirement of one of three options. Option 1 is as follows, “reduce the development footprint (defined as the total area of the building footprint, hardscape, access roads and parking) and/or provide vegetated open space within the project boundary to exceed the local zoning’s open space requirement for the site by 25%. Option 2: for areas with no local zoning requirements (e.g., some university campuses, military bases), provide vegetated open space area adjacent to the building that is equal to the building footprint. Option 3 is defined as where a zoning ordinance exists, but no requirement for open space, provide vegetated open space equal to 20% of the project’s site area” [LEED-NC 2005].

The design engineer has multiple options to obtain this Sustainable Sites, Credit 5.2. Generally the development footprint can be reduced by having parking garages on the lower levels of structural systems such as cast-in-place, precast, tilt-up, reinforced masonry, steel, or wood structural systems. Another option, as used for the Kandalama Hotel located in Damulla, Sri Lanka, is to provide columns to elevate the buildings above the natural features such as boulders and to reduce cut-and-fill needs.¹ This credit is worth 1 point.

4.1.4 *Sustainable sites, credit 7.1, Heat Island Effect – Non-Roof*

The intent of this credit is to minimize the effect on microclimates and in turn the biosphere by means of reducing heat islands from non-roofs. Credit for Heat Island Effect, Non-Roof can be obtained by fulfilling one of two options. Option 1 is listed as follows “Provide any combination of the following strategies for 50% of the site hardscape (including roads, sidewalks, courtyards and parking lots), shade (within five years of occupancy), paving materials with a Solar Reflectance Index (SRI) of at least 29 out of a possible 100, and Open grid pavement system” [LEED-NC 2005].

Option 1, of this credit, can be achieved by using concrete. This is done by using concrete instead of asphalt for a specified portion of all sidewalks, parking lots, drives, and other non-roof impervious surfaces. Concrete works well in this application, containing relatively high albedos. “Albedo is the ratio of the amount of solar radiation reflected from a material to the amount shone on the material” [Vangeem & Marceau 2002]. In general, surfaces containing high albedo are light in color absorbing less energy and thus cooler. Whereas surfaces with lower albedos absorb more solar radiation, that converts into heat, causing the surface to become hotter. Concrete’s reflective surfaces save

¹ Additional information on case studies referenced in this manuscript may be found in “Primary Sustainability Features and LEED Applications of Common Structural Materials” by J.E. Maher 2006.

energy by reducing temperature which in turn cuts air-conditioning usage leading to less power needed and improved air quality. Concrete generally has an albedo or solar reflectance of about 0.35, although values may vary. New asphalt concrete generally has a reflectance of around 0.05 and asphalt concrete older than four years has a reflectance of approximately 0.10 to 0.15 [Vangeem & Marceau 2002]. Though not an obvious application for structural concrete the possibility exists to achieve credit.

Option 2 deals with the structure, "Place a minimum of 50% of parking spaces under cover. Any roof used to shade or cover parking must have an SRI of at least 29 out of a possible 100" [LEED-NC 2005]. Option 2, of this credit, pertains to using parking garages. All four common structural materials discussed in this report can assist in obtaining this option. Meeting the requirements of either option is worth 1 point.

4.1.5 *Sustainable sites, credit 7.2, heat island effect – roof*

The intent of this credit is to minimize the effect on microclimates and in turn the biosphere by means of reducing heat islands due achieve this credit one of the following three options must be fulfilled. To achieve this credit one of the following three options must be fulfilled.

Option 1 is defined as, "use roofing materials having a Solar Reflectance Index (SRI) equal to or greater than 75% of the roof surface" [LEED-NC 2005]. Option 2 is to, "install a vegetated roof for at least 50% of the roof area" [LEED-NC 2005]. Option 3 is as follows, "install high albedo and vegetated roof surfaces that, in combination, meet the following criteria: $(\text{Area of SRI Roof} / 0.75) + (\text{Area of vegetated roof} / 0.5) \geq \text{Total Roof Area}$ [LEED-NC 2005]. Further explanation of high albedo is found in the LEED-NC Version 2.2 Reference Guide.

A possible option for attaining this credit is to install a vegetated roof system. Though indirectly related, the type of structural material used to support this system does depend on the additional loads created from vegetation, spanning requirements, and the architectural design being expressed therefore consideration of the type of structural material used is necessary. The largest known example of a green roof system is currently the Ford Dearborn Truck Assembly located in Dearborn, Michigan. A steel superstructure supports over 4 hectares (approximately 10 1/2 acres) of green roof. A green roof regardless of the structural system is worth 1 point. All four common structural materials can obtain this point as shown in Table 4.

4.2 *Energy & Atmosphere*

Another category listed in Table 3 is Energy & Atmosphere. Prereq 2 and Credit 1 apply to structural

materials. This category implements a number of strategies to help reduce energy use and protect the ozone layer. As pertaining to structural materials, the purpose is to minimize the amount of energy necessary and optimize the energy performance of the structure.

4.2.1 *Energy & atmosphere, prereq 2, minimum energy performance*

The intent of this prerequisite is to establish the minimum level of energy efficiency for the anticipated systems and buildings as required by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1–2004. This is done by maximizing the energy performance of the anticipated systems and building envelope. Once the minimum standard has been met i.e. Prereq 2, then points for the following credit can be obtained.

4.2.2 *Energy & atmosphere, credit 1, optimize Energy Performance*

The intent of this credit is to reduce the impacts (environmental and economical) associated with excessive energy use by going beyond Prereq 2 (acting as the baseline) and achieves incremental levels of energy performance above the requirements of ASHRAE 90.1–2004. The thermal mass of concrete or masonry, when combined with insulating materials, is very useful to achieve points for this credit. Concrete and masonry have the ability to absorb the heat/cold and slowly releasing it thereby reducing temperature swings and energy loads in a building. This lessens the strain on the HVAC system and reduces energy waste. Often a computer program will be used to more accurately capture the beneficial thermal properties of concrete or masonry. This is accomplished by calculating yearly energy usage based on hourly data. Points are awarded based on energy cost savings from 15 to 60% for new buildings. This credit is worth 1–10 points [PCA 2005a].

4.3 *Materials & Resources*

Another rating system category which applies to structural materials is Materials & Resources. This category covers a broad range of credits including Building Reuse, Construction Waste Management, Material Reuse, Recycled Content, Regional Materials, Rapidly Renewable Materials, and Certified Wood. Building materials choices are important in sustainable design because of the extensive network of extraction, processing and transportation steps required to process them. Almost all of the credits available can apply to structural materials.

4.3.1 *Materials & resources, prereq1, storage & collection of recyclables*

The intent of this prerequisite is to reduce the amount of waste, anything that is transported to and disposed

of in landfills, generated by the building occupants. Once the minimum standard has been met i.e. Prereq 1, points for the following credits within the Materials & Resources category can be obtained.

4.3.2 *Materials & resources, credits 1.1 and 1.2, building reuse*

The intent of these credits is to extend the life cycle of existing infrastructure. For new infrastructure, the purpose is to reduce environmental impacts as it applies to the embodied energy of the material by retaining portions of the existing walls, floors, and roof. The following requirements to be met to obtain credit 1.1 are “Maintain at least 75% (based on surface area) of existing building structure (including structural floor and roof decking) and envelope (exterior skin and framing, excluding window assemblies and non-structural roofing material). Hazardous materials remediated as a part of the project scope shall be excluded from the calculation of the percentage maintained. If the project includes an addition to an existing building, this credit is not applicable if the square footage of the addition is more than 2 times the square footage of the existing building” [LEED-NC 2005].

All four common structural materials can be utilized to obtain this credit. Concrete has a long service life and with proper planning, reinforced concrete used in almost any structural system can easily be modified/retained for expansion purposes. Masonry and wood are known for being durable structural materials thus making them ideal for reuse. Steel structures are easily reused because they can be economically adapted and reinforced which permits flexibility and adaptability in the modified use of the structure. To achieve the first point, at least 75% (based on surface area) of the existing structural system must be retained. To attain credit 1.2 an additional 20% (95% total) of the building’s surface area needs to be reused.

4.3.3 *Materials & resources, credits 2.1 and 2.2, construction waste management*

Minimize landfill disposal and incineration of construction debris is the intent of these credits. This is to be accomplished by redirecting reusable materials to suitable sites, and divert recyclable, recovered resources to suitable locations. To fulfill the requirements for credit 2.1 the following must be met, “recycle and/or salvage at least 50% of non-hazardous construction and demolition debris. Develop and implement a construction waste management plan that, at a minimum, identifies the materials to be diverted from disposal and whether the materials will be sorted on-site or commingled. Excavated soil and land-clearing debris do not contribute to this credit. Calculations can be done by weight or volume, but must be consistent throughout the computation process” [LEED-NC 2005]. To obtain credit 2.2 the above requirements for credit 2.1

must be met plus an additional 25% (75% total) of non-hazardous construction and demolition debris is required to be recycled and/or salvaged.

Reinforced concrete is a construction material which is frequently being crushed and recycled into aggregate. Based on this, when any type of structure is demolished one can pursue credit in this category. The modularity of masonry creates less waste in general, because the module limits design and construction possibilities. The waste that does occur from masonry construction can be crushed and recycled. After concrete masonry waste has been crushed, it can be used for aggregate or fill. Crushed clay brick waste can be used as brick chips for landscaping. The masonry units that are intact can be used on another project or donated to a charitable organization [Subasic 2004]. Steel is one of the most recycled materials ensuring that virtually any steel on a construction site can be reused or recycled [Stern et al. 2003]. Wood is known to be a very adaptable building material meaning the ability to often cut on-site, instead of prefabricated which creates construction waste. This construction waste when managed (recycled) will leave little if any impact on the environment. This credit is worth 1 point when at least 50% of non-hazardous construction and demolition debris is recycled and/or salvaged and 2 points given for at least 75%.

4.3.4 *Materials & resources, credits 3.1 and 3.2, materials reuse*

The intent of both credits is to reuse building products and materials in order to decrease the use of virgin materials and reduce waste, lessening the impact associated with their extraction and processing. To achieve credit 3.1, salvaged, refurbished, or reused materials must be used, so that the sum of these products and materials is at least 5% (based on cost) of the total amount of materials on the project. Items not to be included are mechanical, electrical, plumbing, and specialty items. Only materials permanently installed in the project can be included. An extra credit can be achieved if an additional 5% (total of 10%) of the total materials have been salvaged, refurbished, and/or reused [LEED-NC 2005].

Though still emerging, steel reuse is becoming a more common practice and numerous documentations, as mentioned earlier, of using salvaged steel in new, additions, or relocated structures have occurred. Wood has the ability to be salvaged from building deconstruction projects and saved for reuse. “Salvaged wood can be of higher quality than equivalent wood milled today, tending to be denser and to have fewer knots” [Larry McFarland Architects Ltd. 2003]. Another advantage is the manufacturing of heavy timbers, large dimension lumber, and glulam beams tend to be costly making salvaged wood more

advantageous. Unfortunately salvaged wood is not always easy to obtain which is why the United States Department of Agriculture (USDA) Forests Products Lab developed a Directory of Wood-Framed Building Deconstruction and Reused Building Materials Companies [Bland 2005]. Combined, these credits are worth 2 points.

Though both of these credits directly relate to steel and wood, masonry is durable and has the potential to indirectly be reused and salvaged. The Brick Industry Association does warn against their use since reused brick may not meet the requirements of present-day specifications and may not bond properly. Paver brick that are salvaged and used for interior applications on a new building meet the intent of this credit. "However, most masonry units can be reused when carefully dismantled. A good example of this is the Mountain Equipment Co-op building in Winnipeg, constructed using significant amounts of re-used brick" [Masonry Canada 2005].

4.3.5 *Materials & resources, credits 4.1 and 4.2, recycled content*

The intent of both credits is to reduce the impact from extraction and processing of raw materials while increasing the demand for incorporation of recycled material content in buildings. Credit 4.1 is awarded, if the sum of post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% (based on cost) of the total value of the materials in the project. For the purpose of this credit, LEED has defined pre-consumer as material that has been diverted from the waste stream during manufacturing, while explaining post-consumer as all waste generated by some form of human consumption (from factory to household use) that can no longer be used for its intended purpose. Credit 4.2 is achievable by having at least an additional 10% (total of 20% of cost) of materials with recycled content [LEED-NC 2005].

Concrete, clay brick, concrete blocks, reinforcing steel, grout, and engineered lumber can all be produced from at least a portion of recycled materials. Any concrete mix can be partly composed of supplementary cementitious materials (SCMs). Since LEED considers reinforcing steel to be separate from the concrete, using recycled rebar will also help achieve credit. As previously mentioned, the recycled content of steel is one of its greatest advantages. In 2004, according to the Steel Recycling Institute, the EAF and BOF processes used 81% post-consumer recycled content and approximately 16% pre-consumer recycled content. Specifying engineered and composite lumber products that has recycled content also achieves this credit. "Engineered lumber is manufactured by combining wood fibers with plastic resins to produce high quality, structural products such as wood I-joists, laminated veneer lumber

(LVL), parallel strand lumber (PSL), and glulam beams. Sheathing products manufactured in this manner, such as oriented strand board (OSB), wafer board and particle board, are made primarily of saw mill waste. Likewise, finger-jointed lumber made from wood scraps makes use of material that would otherwise be wasted" [Denver AIA 1997].

4.3.6 *Materials & resources, credits 5.1 and 5.2, regional materials*

The intent of these credits is to support the indigenous resources while reducing transportation causing ecological impacts. To achieve 1 point, a minimum of 10% (based on cost of the total material value) of regional building materials must be used. 2 points can be awarded for at least 20%.

Concrete being cast on-site, or at a nearby facility, it is a very viable option for attaining these credits. "Concrete mix plants generally use aggregate that are extracted within 80 km (50 miles) of the plant. Cement and SCMs used for buildings are also often manufactured within much less than 800 km (500 miles) of a job site. Reinforcing steel is usually manufactured within 800 km (500 miles) of a job site, and is typically made from recycled materials from the same region" [PCA 2005a]. Manufacturing facilities for masonry are located all across the nation making these credits readily attainable. Until recently, obtaining credit in the western United States for manufacturing steel within 800 km (500 miles) was difficult. This was because only four locations exist where wide flange sizes, W14x43 and larger, are rolled and all are on the eastern half of the United States. Then a credit interpretation ruling for structural steel, in February 2004, established that "the fabrication shop is considered the location where the final manufacture of the product occurred. Fabricators cut steel members to their appropriate length, punch or drill holes, weld on connection plates, and add the necessary camber to members. Fabricators may also build the steel into standard assemblies, such as trusses or frames. Steel fabricators are available within 800 km (500 miles) of most locations in the United States and the use of local fabricators fosters local economies for the product, which reinforces the intent of the credit" [Stern et al. 2003]. The extracting or harvesting of raw materials within 800 km (500 miles) of the jobsite is more difficult to achieve. For steel this includes the "location where the metal served its last useful purpose before it became scrap. Steel mills typically acquire scrap from brokers, who obtain materials from projects and products throughout the country, which are selected based upon metallurgical needs and cost. Acquiring wood products manufactured within 800 km (500 miles) is usually feasible. The most reliable way to confirm if these credits are attainable is to contact a building material supplier

located near the future building site. All four structural materials may obtain these credits.

4.3.7 *Materials & resources, credit 6, rapidly renewable materials*

The intent of this credit is to utilize rapidly renewable materials, thereby reducing the need for finite raw materials and long-cycle renewable materials. A minimum of 2.5% (of the total value) needs to be from rapidly renewable building materials and products. This credit appears to be easily attainable for wood, but in actuality quite the opposite is true. LEED defines a rapidly renewable material as maximum of a 10-year harvest cycle. Generally only southern states, growing poplar or aspen, are able to meet this requirement due to longer growing seasons. "On a more positive note, OSB and other composite wood products do make extensive use of species, such as aspen or poplar, not traditionally used for lumber, many of which have a potentially much shorter harvest cycle than the species traditionally used for lumber" [Larry McFarland Architects Ltd. 2003]. An example of how this credit could apply structurally is the Solar Living Center in Hopland, California. Wood structures may be awarded 1 point for achieving this credit.

4.3.8 *Materials & Resources, credit 7, certified wood*

The intent of this credit is to promote environmentally conscientious forest management. To achieve this credit, a minimum of 50% of wood-based materials and products need to be used. The entire 50% needs to be certified in accordance with the Forest Stewardship Council (FSC)'s Principles and Criteria, for wood building components. Though FSC certified wood products are available, increased project cost often exists. The FSC provides a Supplier Referral Network website to assist in the process. Wood structures may be awarded 1 point for achieving this credit.

4.4 *Indoor Environmental Quality*

In the Indoor Environmental Quality category, Credits 4.4, 8.1, and 8.2 can apply to structural materials. The importance of this category is that Americans spend an average of 90% of their time indoors, where levels of pollutants may be two to five times higher than outdoor levels. Therefore, the cleaner the indoor environments are the healthier the individuals who use them.

4.4.1 *Indoor Environmental Quality, credit 4.4, low-emitting materials*

The intent of this credit is to reduce the amount of indoor air contaminants that are odorous, uncomfortable, and or dangerous to the well-being of humans. This credit refers to composite wood and agrifiber products that are manufactured using two primary

ingredients: wood fibers or particles, and binders that adhere to the wood particles. Structural wood and agrifiber products include plywood, glued laminated timber (glulam), oriented strand board (OSB), laminated veneer lumber (LVL), laminated strand lumber, parallel strand lumber, and wood I-joists. Any of the aforementioned shall contain no added urea-formaldehyde resins, because urea-formaldehyde resins are carcinogenic and an irritant to most people when present in high concentrations resulting in headaches, dizziness, mental impairment, and other symptoms. Generally this credit, worth 1 point, is easily attainable when using wood products.

4.4.2 *Indoor Environmental Quality, Credit 8.1 and 8.2, daylight & views*

The intent of both of these credits is to introduce daylight and views into the commonly used areas of the building giving the occupants a sense of connection to the outdoors. Structural materials that are able to span longer distances based upon strength and deflection aid in attaining daylight and views in the building. Steel is able to span the longest distances based upon its strength to weight ratio. An example of steel's possibilities is the Capitol Area East End Complex, Block 225 project in Sacramento, California. A 20 m (65 foot) steel girder was employed to span over the main lobby, creating an open space for daylight and views, to assist (among other reasons for using steel) in the project achieving a Gold rating. As a structural material, steel can assist in achieving 2 points for these credits.

4.5 *Innovation & design process*

4.5.1 *Innovation & design process, credits*

1.1, 1.2, 1.3, and 1.4, Innovation in design

The intent of these credits is for innovative green design strategies that do not correspond with any of the five LEED categories or for exceptional performance above the LEED-NC requirements. All four of the common structural materials could possibly attain up to 4 points either directly or indirectly. One possibility is to leave the structural system exposed. Not only does this create a pleasing architectural effect, but decreases the costs of finishing materials.

An aspect to consider when using reinforced concrete in sustainable design is the quantity of formwork required. Formwork is approximately 50% of the cost of reinforced concrete superstructure for a multistory commercial building. As mentioned in Reinforced Concrete, Section 5.0, several forms of reinforced concrete including cast-in-place concrete, precast, concrete, and tilt-up concrete are used in the building industry. Precast concrete uses less formwork since it is not manufactured on-site and typically uses less shoring and no reshoring. Tilt-up concrete is poured in a horizontal position, creating

less surface area to form, also decreasing the amount formwork.

Many sustainable aspects of masonry can be utilized to achieve points not accounted for in the current LEED-NC rating system. A couple advantageous ideas are the acoustical performance attainable using masonry and improved indoor air quality from masonry interior bearing wall systems creating virtually no off-gassing. Another quality to consider is masonry systems resistant to burn. "Masonry is inherently fire resistant and provides fire safety for people. Interior masonry fire partitions help stop the spread of fire. These aspects reduce the environmental impacts of fires. Passive fire protection reduces the costs of buildings" [Masonry Canada 2005]. Note that the aforementioned also applies to reinforced concrete.

Steel is known for being deconstruct-able, recyclable, and reusable. All of these factors can be used to surpass the LEED credit requirements and achieve additional points. Steel being naturally light in weight can also be advantageous in gaining points. In order to attain credits for this, the project team must clearly demonstrate significant savings using a conventional building as a baseline. An excellent example of this is the Utah Olympic Oval in Salt Lake City, Utah. The very shallow steel truss roof is supported by an innovative cable suspension system. The overall arena weighs over 865 tons (950 U.S. tons) less using this system than competing designs [Stern et al. 2003].

Wood has several possibilities for achieving points through innovation. Scraps from wood framing could be turned into wood chips onsite and used for landscaping creating virtually no waste. During the design phase, the architect and engineer need to communicate structural and aesthetical needs. If done correctly, openings for framing will coordinate with the framing module, and using exact stud height could mean a tremendous savings in lumber.

4.5.2 *Innovation & design process, credit 2, LEED accredited professional*

The intent of this credit is supplementary support during the application and certification. This credit is not specific to any structural material. As long as a LEED Accredited Professional is a principal participant of the project team this credit, worth 1 point, is attained.

5 CONCLUSION

As sustainability concerns increase, involvement by structural engineers is vital. The use of engineering knowledge of common and alternative structural materials, coordination of structural systems with mechanical systems, and comprehension of integrated structural systems are essential. Structural engineers having the ability to assess common structural materials and their

sustainability benefits, plays a crucial role essential in sustainable design.

This paper provides the structural engineer with some of the information available to address the sustainability of the four most common structural materials: reinforced concrete, reinforced masonry, steel, and wood as they apply to the LEED-NC Version 2.2 rating system. A comparison of the sustainability of structural materials (including innovations), using the LEED-NC rating system, is provided in Table 4. Based the results in Table 4, reinforced concrete and masonry seem to be the most sustainable structural materials when evaluated by LEED-NC, though all four materials offer significant contributions.

One should consider that not all factors which make a material sustainable are properly represented using the LEED-NC rating system, thereby raising some concern. From a structural aspect, it is difficult to look at the system scoring ballot and tell which points were obtained using structural materials. Currently, the structural system seems insignificant to LEED since it is not mentioned or referred to. This should cause some concern, because the built environment would be non-existent without the support of structural systems. The LEED-NC rating system does not directly consider energy usage (embodied energy) of a material which could increase or decrease the sustainability of the materials. For example, wood, the only naturally occurring and renewable structural material, received the lowest score as shown in Table 4.²

This seems inconsistent with the purpose behind sustainability. Further research needs to be done on how to better integrate structural materials with LEED-NC. Even with these concerns, the rating system has shown all four structural materials can make a significant impact in achieving sustainability. The adage "two minds are better than one" should be adapted to structural materials. By integrating multiple structural systems more LEED-NC points are achievable and often times a more efficient and economical design results.

Sustainability has come a long way over the past decades, as shown by the case studies mentioned in the paper. Though LEED-NC is a good tool for gauging sustainability, it must be realized that no system is perfect. Comprehension and implementation of sustainability is a continual process making it important to take the information provided in this paper, build upon it, and create a continual cycle of sustainable design for future generations. As Dietrich Bonhoeffer, a German theologian, once said, "the ultimate test of a moral society is the kind of world that it leaves to its children."

² For further discussion refer Master's Report entitled "Primary Sustainable Features and LEED Applications of Common Structural Materials" by J.E. Maher, 2006.

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