GREEN BUILDINGS AND STRUCTURAL ENGINEERING

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Summary

Structural engineers design green buildings using the LEED™ Green Building Rating System™, a point-based system for certifying the level of a building's sustainability. Structural materials play a large part in increasing a building's sustainability. Using concrete, for example, can help in brownfield redevelopment, reduce urban heat islands, mitigate water runoff, help meet minimum energy requirements, optimize energy performance, and increase the life of a building. Concrete and its constituents are usually available locally. Both concrete and steel can be recycled. Steel, fabricated in a shop, creates little to no on-site waste and has high recycled content. Attributes of these structural materials, and others, along with decisions made by design professionals help to lessen the impact a structure has on the natural environment.

Keywords: structure, engineering, green, sustainability, concrete, steel

1. Introduction

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. LEED is both a *standard* for certification and a *design guide* for sustainable construction and operation. LEED is administered by the U.S. Green Building Council (USGBC). This paper discusses structural engineering aspects of LEED v3, as they apply to commercial, institutional, and high-rise residential new construction and major renovation.

Essentially, *LEED* is a point-based system that provides a framework for assessing building performance and meeting sustainability goals. Points are awarded when a specific intent is met, and a building is LEED certified if it obtains at least 40 points. The points are grouped into seven categories: (i) sustainable sites, (ii) water efficiency, (iii) energy and atmosphere, (iv) materials and resources, (v) indoor environmental quality, (vi) innovation in design, and (vii) regional priority. Besides the 40 points required for certification, the more points earned, the "greener" the building. Silver, gold, and platinum ratings are awarded for at least 50, 60, and 80 points, respectively.

Decisions made by structural engineers will affect a building's LEED rating. For instance, appropriate use of concrete can help a structure earn up to 32 points out of the 40 required for LEED certification. Using concrete can assist in brownfield redevelopment, reduce urban heat islands, reduce water runoff, help meet minimum energy requirements, optimize energy performance, and increase the life of a structure. Concrete and its constituents are usually available locally. Both concrete and steel can be recycled. Steel and precast concrete, fabricated in a shop, create little to no on-site waste. Attributes of these structural materials, and others along with decisions made by design professionals help to lessen the impact a structure has on the natural environment.

Sustainability is often defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Although most structural engineers are concerned with the present and future health of the natural environment, few clients are willing to pay more for a structure that minimizes environmental burdens. Structural engineers can promote the use of LEED standards to balance sustainable design with cost-effectiveness.

Sustainable design can result in reduced project costs and a structure that is energy and resource efficient. Energy and water efficient buildings have lower operating costs than conventional buildings: in the range of U.S. $6 to $16 versus $19 per m^2. Lower energy costs translate into smaller capacity-requirements for mechanical heating and cooling equipment and lower first costs for such equipment. Effective use of daylighting and passive solar techniques can further reduce heating and cooling costs. Reusing materials, such as recycled concrete for base or fill material, can reduce hauling and landfill costs. If sustainability is an objective at the outset of the design process, the cost of a sustainable building can be competitive [1].

The design professional has the opportunity to inform their clients of the benefits of sustainable structures. Buildings with daylighting and good indoor air quality—both common features of sustainable buildings—have increased labor productivity, worker retention, and days worked. These benefits contribute directly to a company's profits because salaries—which are about ten times higher than rent, utilities, and maintenance combined—are the largest expense for most companies occupying office space. In schools with daylighting and good indoor air quality, students have higher test scores and lower absenteeism.

Many U.S. government agencies require that buildings meet LEED requirements, although they do not necessarily require LEED certification. Some examples include the General Services Administration, which owns or leases over 8300 buildings, and the U.S. Army, which has adopted LEED into its Sustainable Project Rating Tool (SPiRiT). In addition, many municipalities and local government agencies require LEED certification for public buildings or tax credits. [2]

2. The LEED Point System

The most current version of the Green Building Rating System is LEED v3 (2009). The LEED points are grouped into credits that are further grouped into the seven categories mentioned earlier. Many credits are worth 1 point, but some—the ones with a higher potential to reduce environmental impact—are worth more. For all credits, specific auditing or record keeping requirements must be met. A free copy of LEED v3 can be downloaded from the website www.USGBC.org.

3. Green Buildings and Concrete

The use of concrete provides many chances to assist in gaining credits towards a LEED rating.

Sustainable Sites

Brownfield Redevelopment. Cement can be used to make structural embankments that solidify and stabilize contaminated soils and reduce leaching concentrations to below regulatory levels.

Documentation is required indicating the site was contaminated and describing the remediation performed. This credit is worth 1 point.

Stormwater Management: Rate and Quantity. On building sites where the existing imperviousness is greater than 50%, pervious concrete slabs can be used to help reduce the rate and quantity of storm water runoff. The technical requirement for this credit requires reducing the rate and quantity of stormwater runoff by 25%. Pervious concrete contains coarse aggregate (crushed stone or gravel), little or no fine aggregate (sand), and insufficient cement paste to fill the voids between the coarse aggregate. It results in concrete with a high volume of voids (20% to 35%) and a high permeability that allows water to flow through easily as shown in Figure 1. Similar results can be achieved by using concrete pavers that have large voids where vegetation can grow. This credit is worth 1 point.

Figure 1. Water flows through pervious concrete.

Heat Island Effect: Non-Roof. Methods used to attain this credit include incorporating light-colored/high-albedo materials (solar reflectance index, or SRI, of at least 29) at the hardscape surfaces, providing shade from structures having SRI 29 or higher, and using an open-grid pavement system at least 50% pervious for 50% of the site's non-roof hardscape surfaces. This requirement can be met by using portland cement concrete for 50% of all sidewalks, parking lots, drives and other non-roof impervious surfaces. Another method is placing 50% of parking spaces under cover. The cover must consist of SRI 29 or higher material, be a vegetated green roof, or be covered by solar panels. The city of Chicago Public library shown in Figure 2 attained LEED certification using this one point credit.

Figure 2. The City of Chicago achieved LEED certification for this public library with points for concrete sidewalks, among other credits.

Albedo, which in this context is synonymous with solar reflectance, is the ratio of the amount of solar radiation reflected from a material to the amount that shines on the material. Solar radiation includes the ultraviolet as well as the visible spectrum. Generally, light-colored surfaces have a high albedo, but this is not always the case. Surfaces with lower albedos absorb more solar radiation. Absorbed radiation is converted into heat and the surface gets hotter. Pavements with higher albedos absorb less energy and are thus cooler. Where paved surfaces are required, using materials with higher albedos will reduce the heat island effect, saving energy by reducing the demand for air conditioning, and improve air quality.

Portland cement concrete typically has an albedo of approximately 0.35 although values can vary. Measured values are reported in the range of 0.4 to 0.5. For "white" portland cement, values are reported in the range of 0.7 to 0.8 [3]. New asphalt concrete generally has a reflectance of approximately 0.05 and asphalt concrete five or more years old has a reflectance of approximately 0.10 to 0.15.

Heat Island Effect: Roof. To obtain this credit the roofing materials for 75% of the roof must have an SRI of 78 or higher for a low-sloped roof (slope ≤ 2:12) or an SRI of 29 or higher for a steep-sloped roof (slope > 2:12). Materials with a lower SRI can also be used as long as the weighted rooftop SRI average meets the criteria above. Other options to meet the criteria include installing vegetated roof (see Figure 3) or a combination of vegetated roof and high-albedo roof surfaces to meet similar criteria. Of course, the roof structure must be designed to carry weight of the vegetated roof. Equations to calculate the weighted rooftop SRI average are found in LEED v3.

Figure 3. Vegetated roof at Chicago City Hall

Energy and Atmosphere

Minimum Energy Performance. This prerequisite for obtaining Energy and Atmosphere credits requires completion of one of three options. The first option is to perform a "Whole Building Energy Simulation" and demonstrate a 10% improvement in the proposed building rating for new buildings, or a 5% improvement in the proposed building performance rating for major renovations to existing buildings, compared with the baseline performance rating.

To achieve this prerequisite, the energy analysis must comply with the provisions in Appendix G of ANSI/ASHRAE/IESNA Standard 90.1-2007 [4] (with errata but without addenda), include all building energy costs, and compare against a baseline building that complies with Standard 90.1-2007. It is generally economical to insulate to meet or exceed the requirements of the ASHRAE standard. Again, this item is a prerequisite for LEED certification and is not worth any LEED points.

Structures with high thermal mass, such as buildings built of insulated concrete form (ICF), concrete, or concrete masonry units, moderate indoor temperature extremes and reduce peak heating and cooling loads. In many climates, they have overall lower energy consumption than non-massive buildings with walls of similar thermal resistance [5]. Also, heating, ventilating, and air-conditioning can be met with smaller-capacity equipment.

The second and third options for attaining this Minimum Energy Performance are to comply with the prescriptive measures of the appropriate ASHRAE Advanced Energy Design Guide or the Advanced Buildings™ Core Performance™ Guide, respectively.

Optimize Energy Performance. This credit is worth 1 to 19 points. Points are awarded if energy cost savings of at least 12% for new buildings and 8% for existing buildings can be shown when compared to a base-line building that meets the requirements of Appendix G of Standard 90.1-2007 (with errata but without addenda). The method of determining energy cost savings requires modeling a building to determine energy savings using a computer-based program, such as DOE 2 [6] or Energy Plus. When concrete is considered, it is important to use a program like DOE 2 or Energy Plus that calculates yearly energy consumption on an hourly basis. Such programs are needed to capture the beneficial thermal mass effects of concrete. Many analyses that are done free of charge by HVAC manufacturers do not have this capability.

As in the Energy and Atmosphere prerequisite, alternative options for this credit include complying with the ASHRAE Advanced Energy Design Guide (to earn one point) or the Advanced Buildings™ Core Performance™ Guide (to earn one to three points).

Insulated concrete wall systems, used in conjunction with other energy saving measures, are commonly eligible for points. Number of points awarded will depend on the building, climate, fuel costs, and minimum requirements of Standard 90.1-2007. From 1 to 19 points are awarded for energy cost savings of 12 to 48% for new buildings and 8 to 44% for existing buildings.

<u>Materials and Resources</u>

Building Reuse. The purpose of this credit is to encourage reusing the building structure and shell. The structure includes the foundations, slabs, and basement walls. The building shell includes the exterior skin and framing but excludes window assemblies and non-structural roofing material. This credit should be obtainable when renovating buildings with a concrete skin because the concrete components of a building generally have a long life. Structural adaptations and reinforcement are often necessary to accommodate changes in loading conditions. [7] This credit is worth 1 point if 55% of the existing building structure and shell is left in place, 2 points if 75% is left in place and 3 points if 95% is left in place.

Another point is offered for using existing interior nonstructural elements for at least 50% of the entire building area, including additions. These elements include interior walls, floor coverings, and ceiling systems.

Construction Waste Management. This credit is earned for diverting construction and demolition waste from landfills. It is awarded based on diverting at least 50% (by weight or volume but consistent throughout) of the waste materials for a given project. Because concrete is a heavy construction material and is frequently recycled into aggregate for road bases or construction fill [8] [9], this credit is often obtainable when concrete buildings are demolished. Concrete Waste Management is worth 1 point if 50% of the construction and demolition waste is recycled or salvaged and 2 points for 75%.

Materials Reuse. To earn this credit, a portion of total amount of materials on the project must be salvaged, refurbished or reused materials. One point is awarded for 5% (based on cost of the total value of materials on the project) or more salvaged, refurbished, or reused materials and two points for 10% or more. Mechanical, electrical, and plumbing components do not qualify for this credit. It counts only materials permanently installed on the project. Salvaged items such as beams, posts, flooring, paneling and doors should be considered.

Recycled Content. Requirements of this credit state: “use materials with recycled content such that the sum of postconsumer recycled content plus ½ of the preconsumer content constitutes at least 10% or 20%, based on cost, of the total value of the materials in the project.” One point is awarded for at least 10% and 2 points are awarded for at least 20%. The requirement continues, “The recycled content value of a material assembly is determined by weight. The recycled fraction of the assembly is then multiplied by the cost of assembly to determine the recycled content value.”

Sample calculations in the LEED Reference Guide [10] show how to calculate recycled content. Supplementary cementitious materials, such as fly ash, silica fume, and slag cement [11] used as a partial replacement for portland cement are considered pre-consumer. Using aggregates from recycled concrete instead of extracted aggregates qualifies as post-consumer. Concrete in its entirety can be recycled by crushing it into coarse aggregate sized pieces as seen in Figure 4. Because concrete is an assembly, its recycled content should be calculated as a percentage of recycled material on a mass basis. Although most reinforcing bar is manufactured from recycled steel and probably qualifies as postconsumer, it is not considered to be part of concrete.

Figure 4. Recycled concrete can be reused as aggregate for new concrete, as sub-base material, and as erosion control.

Regional Materials. Credit is provided for using materials that are extracted and manufactured within 800 km of a project site. This credit supports the use of indigenous resources and reduces environmental impacts from transportation. If only part of the product or material is extracted, harvested, or recovered and manufactured locally, then only that percentage (by weight) can contribute to the regional value.

This credit is worth 1 point if at least 10% of the materials are regional and 2 points if at least 20% of the materials are regional. Concrete from ready-mix and precast plants typically qualify because they generally use aggregates that are extracted within 800 km of the plant. Most building projects are within 800 km of a ready-mix or precast plant.

Cement and supplementary cementitious materials used for buildings are also generally extracted and manufactured within 800 km of a job site. Reinforcing steel is also usually manufactured within 800 km of a job site, and is often made from recycled materials from the same region.

4. Summary of LEED Points Attained by Using Concrete

Table 1 summarizes the benefits of using concrete specifically to earn LEED points.

Table 1: Summary of Points Where Concrete Use Can Help Increase LEED Ratings of Buildings

Category	Number of points		
	Total possible	Using concrete	
		Number	% of total
Sustainable Sites	26	4	15

Water Efficiency	10	0	0
Energy and Atmosphere	35	19	54
Materials and Resources	14	9	64
Indoor Environmental Quality	15	0	0
Innovation in Design	6	0*	0
Regional Priority	4	0*	0
Total	**110**	**32**	**29**

*More are possible: see text.

Concrete can also be used to get points indirectly. The Pennsylvania Department of Environmental Protection building in Harrisburg, Pennsylvania is LEED Bronze certified and features a concrete floor with low-VOC sealant. This allowed the building to obtain the Low Emitting Materials credit under Indoor Environmental Quality. This type of flooring is also eligible for the Low-Emitting Materials-Flooring Systems credit.

5. Sustainability Characteristics of Concrete Not Recognized by LEED

Concrete, in particular, has other sustainability characteristics that are not recognized by LEED:

- Concrete as exterior walls and roofs is a strong, durable material resistant to building fires and forest fires, hurricanes, and wind. “Safe rooms” constructed of masonry within residences and other buildings offer additional protection. Exterior walls of concrete offer more security to building and home owners and require less maintenance than conventional siding materials.
- Concrete is not damaged by moisture, and generally can “breathe” and dry if not prohibited by other adjacent materials.
- Concrete walls reduce sound transmission and provide quieter residences and offices. Sound barriers on highways are often constructed of concrete and masonry to reduce traffic noise adjacent to residential areas.
- The materials used to manufacture cement (mostly clay and limestone) and concrete (generally cement, crushed rock, gravel, and sand) are abundant in most countries.

6. Green Buildings and Steel

Use of steel as a structural material also has its benefits when seeking LEED points. The potential point values awarded for each category are the same as those based on requirements detailed in the concrete section. Structural engineers have the opportunity to include early consideration of steel related sustainability concepts into their design projects.

Sustainable Sites

Heat Island Effect: Roof. Steel roof construction at a slope greater than 2:12 allows a lower SRI value for the roofing material to obtain the credit.

Energy and Atmosphere

Optimize Energy Performance. Well-designed, insulated structural steel framed buildings provide a tight building envelope that exhibits minimum air loss and therefore better HVAC performance over time. [12] This results in efficient energy use as well as monetary savings.

Materials and Resources

Building Reuse. Reusing the existing steel frame of a structure is advantageous towards earning LEED points. Although the structure may be subject to redesign based on new loading conditions, benefits include lack of demolition, reduced waste, and less energy use for production or recycling processes.

Construction Waste Management. Since steel is fabricated off-site to specific specifications, on-site waste is minimal. Its magnetic properties facilitate steel's ease of separation from other materials. LEED encourages contractors to improve their collection methods at the job site to minimize the steel that makes it to landfills [12].

Materials Reuse. Permanently installed steel components can be reused to earn these points. This can include beams, columns, cladding, and stairs. The materials can be reused on the same or at a different site with varying amounts of rework.

Recycled Content. According to the Steel Recycling Institute (SRI) and the American Institute of Steel Construction (AISC), the production of structural shapes includes about 95% recycled content. Almost 100% of structural steel components (beams and plates) used in construction is recycled. The steel industry has been recycling for 150 years since it makes sense environmentally and economically. Using recycled steel does not compromise its desirable qualities and is less expensive than mining and processing iron ore. The recycled content of steel is available from SRI and AISC.

Regional Materials. The final manufacture location for structural steel is the fabrication shop where steel members are cut, drilled, and assembled. Structural steel fabricators are likely to be located within 500 miles (800 km) of any site in the United States [7].

Design for Adaptability and Deconstruction

A design professional can plan a design to create opportunities for future green buildings. By designing for adaptability and deconstruction, the engineer plans not only for a structure's near future, but for the long-term role of its components. A structure should be adaptable to facilitate ease of alteration and amendment. Deconstruction is taking a building apart in such a way that those parts can be reused. Designing for adaptability and deconstruction allows buildings to be easily altered and taken apart by using the most time and energy efficient methods.

A brief summary of Edmonds and Gorgolewski's lists of design topics to consider for adaptability and deconstruction is as follows:

Adaptability [13]

- Use simple structural grid lines
- Allow some redundancy and over-strength to make changes simple
- Separate structure and cladding for independent replacement
- Increase floor to ceiling heights to provide easy adaptive reuse
- Design each component so it can be easily removed and recycled

Deconstruction [13]

- Use durable components
- Provide efficient building deconstruction plan
- Consider the building to have layers defined by life-span of components
- Use prefabricated components assembled on-site that can be disassembled
- Consider connections that can be removed such as bolts, rather than welding
- Provide sufficient space and capacity to accommodate machinery for dismantling

7. Green Buildings and Wood

Wood construction can contribute to the acquisition of three categories of LEED credits.

Materials and Resources

Regional Materials. Especially in the northern and southeast regions of the United States, obtaining wood members from locations less than 800 km from the project is easily feasible.

Rapidly Renewable Materials. Wood can qualify for this one point credit if it is harvested within a 10-year or shorter cycle.

Certified Wood. This credit states that by using "a minimum of 50% (based on cost) of wood-based materials and products that are certified in accordance with the Forest Stewardship Council's principles and criteria for wood building components," one point is earned. At a minimum, these components include structural framing and general dimensional framing, flooring, sub-flooring, wood doors and finishes.

Wood purchased for temporary use on the project, such as formwork, bracing, scaffolding, sidewalk protection, and guard rails, does not qualify.

8. Green Buildings and Masonry

Concrete masonry can benefit a green building by helping achieve sustainable sites, optimize energy performance, and being recycled or produced from recycled materials.

Sustainable Sites

Heat Island Effect: Non-Roof. The use of concrete masonry can provide high-albedo surfaces or an open-grid pavement system that is less than 50% impervious, as required by this credit.

Energy and Atmosphere

Optimize Energy Performance. Concrete masonry has a thermal mass that reduces variations in temperature, stores heating/cooling, and reduces peak energy loads. These attributes reduce a building's HVAC requirements.

Materials and Resources

Building Reuse. The reuse of existing exterior structural concrete masonry walls qualifies for this credit. Non-structural and flooring can contribute to the additional point for interior, non-structural components.

Construction Waste Management. Broken pieces of concrete masonry can be recycled for use as aggregate or infill as structural concrete can. Units left intact can either be reused or donated to charitable organizations in need of construction materials. [14]

Material Reuse. The Brick Industry Association warns against the structural reuse of masonry units due to potential changes in requirements since original manufacture. These units can be salvaged and utilized for non-structural applications. [14]

Recycled Content. Masonry units are ideal for obtaining the recycling credit. Like concrete, concrete masonry units can be made of recycled supplementary cementitious materials like fly ash and silica fume. Also, concrete masonry can include post-consumer materials as aggregate.

Regional Material. In many locations, masonry units are manufactured within 800 km of the site of implementation.

9. Other Design Related Credits

Innovation in Design

Path 1: Innovation in Design. Five points are available under the first path of Innovation in Design credit. These points can be applied for if an innovative green design strategy is used that does not fit into the point structure of the other LEED v3 categories.

Path 2: Exemplary Performance. If a design goes significantly beyond a credit requirement, such as achieving double the credit requirement, up to three exemplary performance points can be earned. For example, the USGBC has issued a credit interpretation that allows for an innovation credit if 40% of the cement in concrete is replaced with fly ash. However, using fly ash in this range is not common, so additional precautions should be considered [15].

Eckmann, et al. describe potential uses of steel as Innovation in Design [7]. The structure itself can be used as the finished surfaces, efficient designs can be used to minimize heating and cooling, planning can provide for easy disassembly, and, more specifically, the structure can be used (in the form of hollow structural sections) as the plumbing system, done by Foster and Partners in the Greater London Authority.

LEED Accredited Professional. One point is awarded if at least one principle participant of the project team is a LEED Accredited Professional. To become a LEED-accredited professional, or LEED AP, the interested party must take and pass a two-part exam facilitated by the Green Building Certification

Institute. The first part is the LEED Green Associate exam which tests general green building knowledge and the second is the LEED Accredited Professional (LEED AP) exam requiring a chosen specialty based on one of the LEED rating systems: Operations and Maintenance, Homes, Building Design and Construction, Interior Design and Construction, or Neighborhood Development (available 2010). These two exams may be taken together or separately.

Regional Priority

Four points maximum can be earned for as many as four Regional Priority credits achieved. These credits are identified by the USGBC regional councils and chapters and stress the importance of certain credits to their specific regions. A list of these credits can be found at www.USGBC.org and are organized by zip code.

10. Final Comments and Conclusions

Structural engineers have the opportunity to keep factors associated with LEED compliance in the forefront of their design method. LEED categories where structural factors can have the most impact include Energy and Atmosphere as well as Materials and Resources. Efficient design, planning ahead, and being aware of sustainability opportunities allow for successful green building construction.

Each building material mentioned, concrete, steel, wood, and masonry, can be used by a designer to attain the ultimate goal of designing a green building. The points awarded can help a building become LEED certified or help a building obtain a higher level of certification. A sustainable design can take advantage of the benefits of structural materials to lessen a building’s impact on the natural environment.

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