Development of a Rating System for Sustainable Bridges

By

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ABSTRACT

One of the latest trends in engineering is sustainable design, which is designing so that resources are available for many generations to come. Sustainable design considers the ecological, economic, and socio-cultural environments and works to balance all three.

Sustainable bridge design is still in development, and clear standards and recommendations have not been formalized as they have in building design. The U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED™) Green Building Rating System evaluates sustainable building design by awarding points based on measurable criteria. The LEED™ rating system deals with buildings, but a similar system could be developed that would apply to bridge design.

This report proposes a rating system for sustainable bridge design based on current practices and emerging technologies. Three bridges (either new or under construction) were rated using the system and the results are presented. Also discussed are steps and obstacles for implementation.

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1. Introduction

One of the latest trends in engineering is sustainable design, which has been described as designing for long term compatibility with the ecological, economic, and socio-cultural environments (Maydl 2004). It is practicing responsible design and construction so that resources will be available for the next generation, and for many generations to come.

Sustainable design sounds great in theory, but there is often difficulty when it comes to implementation. Design codes are often vague and offer few specifics as to how to achieve sustainable design. Engineers are just now being taught how to incorporate sustainability into design, as the concept of sustainable design is relatively new.

This report focuses on the development of a rating system for sustainable bridge design. The rating system will be based on current practice and emerging technologies, and will be modeled after the U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED™) Green Building Rating System (LEED-NC Version 2.1 2001). LEED™ was developed to provide a “common standard of measurement” for sustainable buildings and now provides rating schemes for new construction, existing buildings, commercial interiors, core and shell projects, homes, and neighborhood development (USGBC 2005). Many types of buildings and building construction have been considered under LEED™, but the system does not include structures other than buildings.

The same approach taken by LEED™ could be applicable to bridge design and construction. A rating system based on points given for specific criteria of bridge design would give designers a tool to use to achieve a sustainable design. Such a rating system would also provide a standard for sustainable bridge design and promote sustainable design practices within the engineering profession and beyond.
2. Scope

The rating system developed in this report is most applicable to long-span bridges, as they require the most site preparation and use the most material. Therefore, they are likely to have the largest environmental impact and the largest benefit from sustainable design. Also, smaller-span bridges are not likely to want to take on the additional time and costs that the rating system could entail.

A guideline for bridges eligible to be rated using this system could be based on the main span length, the total length, or a combination of the two. By making the prerequisite length based only on main span length, a bridge that might benefit from the rating system could be left out. An example of a bridge that could benefit from this system but might be excluded based only on main span length criteria is the Chesapeake Bay Bridge in Virginia. The total bridge length is 79,200 ft, but the longest single span is only 100 ft. This type of bridge would not meet a requirement based on main span alone, but could benefit from the use of a rating system. Therefore the rating system requirements should be based on both main span and total span length.

This report proposes using a required length for the main span length greater than 500 ft or a total span length greater than 1000 ft as minimum criteria for rating. This would incorporate many of the applicable bridges, while eliminating most simple-span highway bridges. However, even bridges that do not meet the minimum criteria to be rated can benefit from many of the ideas incorporated in the rating system.

The goal of this rating system is to encourage and recognize good sustainable bridge design by providing cost-effective, measurable guidelines for design and construction. Additionally, promoting sustainable design concepts would foster positive impacts on the natural and cultural environment.

The goals of this rating system are:

- To provide a common standard of measurement for sustainable bridges
- To promote integrated bridge design practices
- To promote sustainable bridge design
- To provide strategies for achieving sustainable bridge design
- To recognize environmental leadership in the bridge industry
3. Implementation

Environmental issues are often secondary during the bridge design process. Conventional wisdom would state that as long as the minimum environmental requirements are met, then the design can be approved. This mindset needs to be changed for sustainable bridge design to be effective.

Currently, bridges are designed to optimize strength and deflection requirements with economy; sometimes aesthetics can be the determining factor in selecting an option among acceptable designs. There are often many solutions for spanning between two points, but it is usually the least expensive option that is selected.

For sustainable bridge design to be successfully implemented there would need to be a paradigm shift away from using economy as the main determinant in bridge design.

Instead, a greater importance needs to be put on environmental factors, even if addressing these factors increases bridge cost. Societal norms need to change in order to place an increased emphasis on the environment in design and construction. The United States and the world as a whole are slowly moving in this direction, but more change is needed in order to achieve the desired results.

A sustainable design would balance environmental and economic costs. A design that is too expensive will never be built no matter how environmentally beneficial it is. However, a slightly more expensive design that incorporates environmental sustainability should be desirable, and may be acceptable.

Any similar bridge rating system is likely to encounter initial opposition due to a perceived increased initial cost. For environmentally sustainable buildings, it has been shown that there are savings in operational energy costs as well as increases in worker productivity. However, there has been no similar demonstration in operating cost savings for bridges. Using operational energy cost savings as a criterion for bridge design is not applicable because the amount of energy bridges use during operation is negligible. As bridges do not technically “use” energy during use, the only similar comparison for operating costs could be maintenance efforts required to keep the bridge in operation.

It is possible that a more environmentally sustainable bridge could cost more than a standard bridge. This means that State governments, or other owners, would potentially have to spend more to design and construct an environmentally sustainable bridge. However, by looking at a whole-life cost that includes maintenance and replacement over the entire life, it may be possible that a sustainable design that has a higher cost up-front may have a cost savings over its lifespan. There may also be additional funding for sustainable designs available from Federal and State Transportation Agencies that could offset the higher initial costs.
Sustainable design should not be solely based on economical considerations, but should also incorporate environmental concerns. Environmental considerations need to be incorporated into engineering design in the same integral way that economic considerations are in order to insure that there are resources for the next generation, and for many generations to come. One way to do this would be to use the bridge rating system developed in this report.

In order for a sustainable design system to be effective, it would need to be implemented on a large scale. This would ideally be at some government level, either state or federal. It could be adopted into the specifications for bridges at a state level or perhaps as a requirement for bridges receiving federal funding. It would need to be done on a wide scale such as this as opposed to a per project basis in order to have a significant effect on the environment, which is the ultimate goal.

For sustainable design, socio-cultural impacts need to be considered in addition to economic and environmental impacts. These could include the impacts from site selection. Demolishing a historic bridge is not culturally sustainable and the decision of where to place the bridge has a large impact on local residents and on who uses the bridge. Socio-cultural impacts can also come from lane use. Allowing for pedestrian and bike lane or transitways can have a huge socio-cultural impact. Long-span bridges can also have an effect on commute times and local tourism.
4. Existing Environmental Requirements

The majority of environmental legislation comes from the National Environmental Policy Act (NEPA) (42 U.S.C. 4321-4347). NEPA, enacted in 1969, is the basic national charter for protection of the environment. It establishes policy, sets goals, and provides a means for carrying out the policy. NEPA not only deals with the natural environment, but with the human environment as well.

The environmental documents that need to be created in order to meet the National Environmental Policy Act (NEPA) requirements are essential for any federally funded or permitted construction project to take place. The first step in the environmental planning is to identify the environmental considerations such as land use, water quality, threatened and endangered species, archeological significance, and cumulative impacts. The next step is to classify the project based on its impacts. The classifications are as follows:

- **Class I** – Actions that significantly effect the environment. A full Environmental Impact Statement (EIS) is required
- **Class II** – Actions that do not individually or cumulatively have a significant environmental effect. Must be approved as a Categorical Exclusion (CE) by the Division Engineer.
- **Class III** – Actions in which the significance of the environmental impact are not clearly established. An Environmental Assessment (EA) is required to determine the significance of the environmental impacts.

**NEPA Documents**

An Environmental Impact Statement (EIS) addresses all reasonable alternatives for a project and predicts all of the impacts the project will create. An EIS is a “full disclosure” document, which means that all data and analysis for the project must be included. The EIS ensures that the project is in compliance with all laws by obtaining proper documentation from other agencies, such as a Record of Decision (ROD) from an implementing agency such as the Federal Highway Administration. All impacts must be determined and a mitigation plan is included in the EIS to make sure that any impacts are properly alleviated. Because an EIS is created when a project will significantly affect the environment, the process can be very complicated and take up to ten years, or more, to complete.

A Categorical Exclusion (CE) is generally used for simple projects such as pavement overlays. Environmental issues are identified, but there are no significant environmental effects from the project. A formal document recognizing this fact, called a Finding of No Significant Impact (FONSI) is issued by the implementing agency at the conclusion of the NEPA process in this situation. Reasonable alternatives are considered, including the No Action alternative, but there are generally fewer alternatives looked at than would be with a Class I project. Because Class II projects normally involve very moderate types of
improvements to existing facilities with minimal environmental effects, a CE generally only takes a few months to complete and the project can then move ahead.

An Environmental Assessment (EA) is written for any project where the environmental impacts are unknown. Data is collected and it is determined if there will be significant environmental impacts. If there are no significant impacts, a Finding of No Significant Impact (FONSI) is documented and the project proceeds. However, if it is determined from the EA that there are significant impacts, the project becomes a Class I project and an EIS must be written.

A long-span bridge that would meet the length requirement to use the rating system would have a significant impact on the environment and would be categorized as a Class I project. An EIS would therefore be required and all plausible environmental impacts would need to be identified before the bridge could be constructed.

Requirements

Many of the major regulations for construction are covered under the EPA Clean Water Act (CWA) (33 U.S.C. ss/1251 et seq. (1977)) and Clean Air Act (CAA) (42 U.S.C. s/s 7401 et seq. (1970)). These acts set minimum standards for water and air quality that cannot be violated during the construction or operation of any project.

Construction projects must also comply with the National Historic Preservation Act of 1966 (NHPA). Section 106 requires projects to take into account the effects of their undertakings on historic properties (16 U.S.C. 470 et seq. (1966)), and section 4(f) requires that special effort should be made to preserve the natural beauty of the countryside and public park and recreation lands, wildlife and waterfowl refuges, and historic sites.

Projects must also comply with the U.S. Fish and Wildlife Service Endangered Species Act (ESA) (7 U.S.C. 136; 16 U.S.C. 460 et seq. (1973)), which protects the habitats of endangered and threatened species.

Although it is a last alternative, many of these acts allow for mitigation in kind. For the endangered species act this could mean creating new habitat elsewhere if habitat is destroyed. For the historic preservation act this could mean moving a historic bridge or rebuilding a replica at a nearby location. However, mitigation does not always have the same effect on the environment as the original.
5. Development of new requirements

5.1. Method

For buildings, the largest environmental impacts come from location, energy and water use, and indoor environmental quality. Most of the LEED™ requirements deal directly with these factors. However, bridges are very different as they do not use much energy once built or have an indoor climate. Many of the sustainable design principles that were developed for buildings are not directly applicable to bridges.

The largest environmental impacts for bridges are the location, materials, and traffic using the bridge. The principles used for determining the criteria for this rating system were:

Minimize location impacts by:
- Choosing sites that tie directly into existing routes
- Not using virgin sites
- Not affecting historic sites

Minimize material impacts by:
- Reducing material needed
- Using material with a lower embodied energy
- Using recycled material and recycling wastes
- Allowing for future expansion

Minimize traffic impacts by:
- Providing HOV lanes
- Providing bike and pedestrian lanes
- Reduce time cars are idling

Other criteria were also added when applicable.

It is important that the criteria used be meaningful, measurable, and cost effective. They must also go above and beyond current requirements. It is inconsequential to award points for criteria that are already met under existing regulations.
All criteria must be:

**Meaningful** – The rating criteria should have a direct positive environmental impact. A large part of successful sustainable design is demonstrating the advantages to the owner of the project and getting them to endorse the idea.

**Measurable** – The rating criteria must be quantifiable. One of the difficulties in developing a rating system such as this is developing quantitative criteria from qualitative concepts.

**Cost Effective** – The rating criteria should be relatively cost effective. The criteria with high economic costs should also have high environmental impacts to offset the expenses. There may also be additional funding available for sustainable design. A few examples are: the Department of Transportation provides funding for bicycle and pedestrian facilities and the Environmental Protection Agency and state environmental programs may provide funding for “brownfield” redevelopment.

Many criteria were analyzed and 18 were selected and assigned point values ranging from 1-3 points (see section 5.3). From the 18 criteria in the bridge rating system, there are 25 points possible. The points are divided between the following 5 categories:

- **Sustainable Sites**: 5 points
- **Traffic Efficiency and Alternative Transportation**: 9 points
- **Water and Energy Efficiency**: 2 points
- **Materials and Resources**: 6 points
- **Innovation and Design**: 3 points

Total: 25 points
5.2. **Criteria**

The following are the criteria under the 5 categories of sustainable design. For each criterion, the intent is given, along with the quantitative requirements, followed by potential technologies and strategies for achieving the requirements.

The criteria are:

**Sustainable Sites**
- Erosion and Sedimentation Control
- Brownfield Redevelopment
- Historic Site Improvements
- Footing and Pier Location

**Traffic Efficiency and Alternative Transportation**
- Lane Adaptability
- HOV Lanes & Transitways
- Bike and Pedestrian Lanes
- Tollbooth Transponders

**Water and Energy Efficiency**
- Stormwater Management
- Green Power

**Materials and Resources**
- Life Cycle Assessment
- Construction Waste Management
- Material Reduction
- Regional Materials
- Certified Wood
- Gray Water
- Cement Replacement

**Innovation in Design**
- Innovation in Design
Sustainable Sites

Erosion and Sedimentation Control
(This credit is taken directly from LEED™)

**Intent:**
Control erosion to reduce negative impacts on water and air quality.

**Requirements:**
Design a sediment and erosion control plan, specific to the site that conforms to United States Environmental Protection Agency (EPA) Document No. EPA 832/R-92-005 (September 1992), Storm Water Management for Construction Activities, Chapter 3, OR local erosion and sedimentation control standards and codes, whichever is more stringent. The plan shall meet the following objectives:

- Prevent loss of soil during construction by stormwater runoff and/or wind erosion, including protecting topsoil by stockpiling for reuse.
- Prevent sedimentation of storm sewer or receiving streams.
- Prevent polluting the air with dust and particulate matter.

**Potential Technologies & Strategies:**
Adopt an erosion and sediment control plan for the project site during construction. Consider employing strategies such as temporary and permanent seeding, mulching, earth dikes, silt fencing, sediment traps and sediment basins.

Although the erosion control is required by the EPA, it is helpful to have a formalized control plan to minimize the chance of accidents.

Brownfield Redevelopment
(This credit is taken directly from LEED™)

**Intent:**
Rehabilitate damaged sites where development is complicated by real or perceived environmental contamination, reducing pressure on undeveloped land.

**Requirements:**
Develop on a site documented as contaminated (by means of an ASTM E1903-97 Phase II Environmental Site Assessment) OR on a site classified as a brownfield by a local, state or federal government agency. Effectively remediate site contamination.

**Potential Technologies & Strategies:**
During the site selection process, give preference to brownfield sites. Identify tax incentives and property cost savings. Develop and implement a site remediation plan using strategies such as pump-and-treat, bioreactors, land farming and in-situ remediation.
** Historic Site Improvements **

** Intent:**
Avoid development of historic sites and reduce the socio-cultural environmental impact from the location of a bridge on a site.

** Requirements:**
Do not demolish any historical bridge as defined by Section 106 of the National Historic Preservation Act. Historic bridges may be moved to an alternative site within 50 miles provided that the site has improved facilities and public access compared to the original site.

If the bridge structure is being built on a historic site or spans over a historic site, improvements shall be made to the facilities and/or access to the site.

** Potential Technologies & Strategies:**
During the site selection process, avoid locating bridges on historic sites or sites which require a historic bridge to be removed.

** Footing and Pier Location **

** Intent:**
Avoid placing footings and piers in waterways and reduce the environmental impact from the location of a bridge on a site.

** Requirements:**
Do not place any part of the bridge structure within a waterway. This will avoid potential impacts from construction as well as changes to the water flow.

** Potential Technologies & Strategies:**
During the site selection process, give preference to sites that allow all bridge structure to be placed on land. Make use of shorter crossing distances and the topography of the land to find appropriate sites.
Traffic Efficiency and Alternative Transportation

Lane Adaptability

Intent:
Provide the framework for additional lanes to be built for unforeseen future conditions. Avoid the need for additional bridges at nearby locations by providing additional capacity if needed.

Requirements:
Design the bridge so that two or more travel lanes can be added without strengthening the substructure. Develop preliminary construction plans for the addition of lanes in the future.

Potential Technologies & Strategies:
Design all structural elements so that they can bear the additional load created by the added lanes. This can be accomplished by using high performance materials, additional material, or higher strength materials.

HOV Lanes & Transitways

Intent:
Promote use of alternative transportation through High Occupancy Vehicles (HOVs) and transit.

Requirements:
Provide one or more transitways or one or more travel lanes in each direction of traffic to be used exclusively by at least one of the following HOVs:

- Buses
- 2 or more person carpools

Potential Technologies & Strategies:
Construct transitways to be used by public light rail or bus. Or designate travel lanes as exclusive HOV lanes. Identify sources of additional funding (i.e. Federal Transit Agency, regional transit agencies).
Bike and Pedestrian Lanes

**Intent:**
Promote use of alternative transportation through bicycles and walking.

**Requirements:**
Provide access and bike lanes and sidewalks for pedestrians. There are 2 points possible, 1 point for providing bike lanes and 1 point for providing sidewalks.

**Potential Technologies & Strategies:**
Develop plans to include both sidewalks and bike lanes. Identify additional funding from Department of Transportation. The Department of Transportation, under TEA-21 (Transportation Equity Act of the 21st Century) reaffirmed their commitment to bicycling and walking and allows funds from programs such as Congestion Mitigation and Air Quality (CMAQ) Improvement, Transportation Enhancements, and the National Highway System to be used for bicycling and walking improvements.

Tollbooth Transponders

**Intent:**
To reduce the impact from cars stopped at tollbooth stations

**Requirements:**
There are two points possible:
- 2 points: No tollbooths on the bridge
- 1 point: If there is a toll booth, 50% of the lanes must be exclusive transponder lanes, accepting only cars with electronic transponder payment systems

**Potential Technologies & Strategies:**
Use transponder technologies such as EZPass (multiple states including NY, PA, DE, MD and others) or FastLane (MA) to allow traffic to move quickly through tollbooths. When possible use systems that allow for higher speeds that are closer to the traveling speed on the bridge.
Water and Energy Efficiency

**Stormwater Management**
(This credit is taken directly from LEED™)

**Intent:**
Limit disruption of natural water flows by eliminating stormwater runoff, increasing on-site infiltration and eliminating contaminants.

**Requirements:**
Construct site stormwater treatment systems designed to remove 80% of the average annual post-development total suspended solids (TSS) and 40% of the average annual post-development total phosphorous (TP) based on the average annual loadings from all storms less than or equal to the 2-year/24-hour storm. Do so by implementing Best Management Practices (BMPs) outlined in Chapter 4, Part 2 (Urban Runoff), of the United States Environmental Protection Agency’s (EPA’s) *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*, January 1993 (Document No. EPA-840-B-92-002) or the local government’s BMP document (whichever is more stringent).

**Potential Technologies & Strategies:**
Capture and treat the stormwater runoff from the bridge. Design mechanical or natural treatment systems such as constructed wetlands, vegetated filter strips and bioswales to treat the bridge’s stormwater.

**Green Power**
(This credit is taken directly from LEED™)

**Intent:**
Encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis.

**Requirements:**
Provide at least 50% of the bridge’s electricity (for lighting, etc.) from renewable sources by engaging in at least a two-year renewable energy contract. Renewable sources are as defined by the Center for Resource Solutions (CRS) Green-e products certification requirements.

**Potential Technologies & Strategies:**
Determine the energy needs of the bridge and investigate opportunities to engage in a green power contract with the local utility. Green power is derived from solar, wind, geothermal, biomass or low-impact hydro sources. Green power may be procured from a Green-e certified power marketer, a Green-e accredited utility program, through Green-e certified Tradable Renewable Certificates, or from a supply that meets the Green-e renewable power definition. Visit www.green-e.org for details about the Green-e program.
Materials and Resources

Life Cycle Assessment

Intent:
Evaluate alternatives based on whole-life environmental costs

Requirements:
Perform a Life Cycle Assessment (LCA) on at least three alternatives. It is not required that the lowest life cycle cost option be chosen, only that designers are aware of the potential environmental cost of each option.

Potential Technologies & Strategies:
LCA is a "cradle to grave" approach that looks at the environmental impacts of raw material extraction, material manufacturing, construction, energy use during lifetime, and end of life deconstruction. It is a "rational, quantified approach to determining specific environmental impacts" (Webster, 2004), which include both the resources used and the waste products created.

Construction Waste Management
(This credit is taken directly from LEED™)

Intent:
Divert construction, demolition and land clearing debris from landfill disposal. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.

Requirements:
Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage at least 50% of construction, demolition and land clearing waste. Calculations can be done by weight or volume, but must be consistent throughout.

Potential Technologies & Strategies:
Establish goals for landfill diversion and adopt a construction waste management plan to achieve these goals. Consider recycling land clearing debris, cardboard, metal, brick, concrete, plastic, and clean wood. Designate a specific area on the construction site for recycling and track recycling efforts throughout the construction process. Identify construction haulers and recyclers to handle the designated materials. Note that salvage may include donation of materials to charitable organizations such as Habitat for Humanity.
Material Reduction

Intent:
Reduce the material demand on the environment.

Requirements:
Reduce the total material required for the bridge by 25%. The reduction can come from structural materials and construction materials, including temporary structures. This reduction may also include materials replaced by recycled material. Calculations can be done by weight or volume, but must be consistent throughout.

Potential Technologies & Strategies:
Use High Strength or High Performance Materials to reduce the amount of required structure. Reuse formwork, temporary bracing, and scaffolding.

Regional Materials
(This credit is taken directly from LEED™)

Intent:
Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the regional economy and reducing the environmental impacts resulting from transportation.

Requirements:
Use a minimum of 20% of building materials and products that are manufactured* regionally within a radius of 500 miles.

* Manufacturing refers to the final assembly of components into the building product that is furnished and installed by the tradesmen. For example, if the hardware comes from Dallas, Texas, the lumber from Vancouver, British Columbia, and the joist is assembled in Kent, Washington; then the location of the final assembly is Kent, Washington.

Potential Technologies & Strategies:
Establish a project goal for locally sourced materials and identify materials and material suppliers that can achieve this goal. During construction, ensure that the specified local materials are installed and quantify the total percentage of local materials installed.
**Certified Wood**
(This credit is taken directly from LEED™)

**Intent:**
Encourage environmentally responsible forest management.

**Requirements:**
Use a minimum of 50% of wood-based materials and products, certified in accordance with the Forest Stewardship Council’s Principles and Criteria, for wood building components including, but not limited to, structural framing and general dimensional framing, and non-rented temporary construction applications such as bracing, concrete form work and pedestrian barriers.

**Potential Technologies & Strategies:**
Establish a project goal for FSC-certified wood products and identify suppliers that can achieve this goal. During construction, ensure that the FSC-certified wood products are installed and quantify the total percentage of FSC-certified wood products installed.

**Gray Water**

**Intent:**
Reduce the need for treated water

**Requirements:**
Use a minimum of 50% gray water in production of ready mixed concrete in accordance with the guidelines and requirements established in ASTM C94.

**Potential Technologies & Strategies:**
Gray water can come from wash water or from surplus concrete separated into clean aggregates and gray water consisting of water, cement/pozzolan fines, ultrafine aggregate particles, and residual admixtures).
Cement Replacement

Intent:
Reduce the CO$_2$ emissions created by cement production

Requirements:
Replace a minimum of 20% (by weight) of Portland cement to be used with byproduct cementitious material such as fly ash, silica fume, or ground granulated blast furnace slag (GGBFS).

Potential Technologies & Strategies:
Replacement cementitious materials can have positive effects on concrete properties. Fly ash, a byproduct of coal combustion, reduces the heat of hydration and improves durability without reducing strength. It is theoretically possible to replace 100% of cement with fly ash, but studies have shown that the optimum replacement level is around 30% (Meyer, 2004). Fly ash is widely available and less expensive than Portland cement.

GGBFS is less available than fly ash, and the cost is comparable to Portland cement. The optimum cement replacement level is between 70 and 80% (Meyer, 2004). A blend of fly ash, GGBFS and Portland cement has been used successfully.

Silica fume, a byproduct of the semiconductor industry, improves both strength and durability of concrete and is often used in high performance concrete. Its higher cost is generally offset by the strength gain.
Innovation in Design

Innovation in Design
(This credit is taken directly from LEED™)

**Intent:**
To provide design teams and projects the opportunity to be awarded points for exceptional performance above the requirements set by the rating system and/or innovative performance in categories not specifically addressed by the rating system.

**Requirements:**
In writing, identify the **intent** of the proposed innovation credit, the proposed **requirement** for compliance, the proposed **submittals** to demonstrate compliance, and the **design approach** (strategies) that might be used to meet the requirements. There will be one credit awarded per approved innovation, up to 4 credits total.

**Potential Technologies & Strategies:**
Substantially exceed a performance credit such as the water and energy efficiency. Apply strategies or measures that are not covered by the rating system such as community development.
5.3. Ratings

The rating criteria developed in the previous section have different levels of impact and different economic costs associated with them. If all criteria had an equal weight, then designers may use only those criteria that have a low economic cost, just to get certification, rather than using the criteria that have the largest environmental impact. In order to encourage sustainable design that has the largest environmental impact, the point system was assigned so that criteria with a higher impact have larger point values.

It was decided that the life cycle analysis (LCA) criteria should be a requirement rather than assigned a point value. This is because it is a good basis for sustainable design and should always be included.

The point values can be seen in Table 1. Also included in Table 1 are the relative economic costs (compared with a standard design), whether the criteria is also a LEED™ credit, and whether there is potential for additional funding from outside sources (i.e. Department of Transportation, Federal Transit Agency, etc.).

<table>
<thead>
<tr>
<th>Credit</th>
<th>Points Possible</th>
<th>LEED credit</th>
<th>Economic Cost</th>
<th>Potential Outside Funding</th>
</tr>
</thead>
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<td><strong>Sustainable Sites (5 points)</strong></td>
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<td></td>
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<tr>
<td>Erosion and Sedimentation Control</td>
<td>1</td>
<td>Yes</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td>Brownfield Redevelopment</td>
<td>2</td>
<td>Yes</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Historic Site Improvements</td>
<td>1</td>
<td>No</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Footing and Pier Location</td>
<td>1</td>
<td>No</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td><strong>Traffic Efficiency and Alternative Transportation (9 points)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane Adaptability</td>
<td>3</td>
<td>No</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>HOV Lanes</td>
<td>2</td>
<td>No</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
<tr>
<td>Bike and Pedestrian Lanes</td>
<td>1 or 2</td>
<td>No</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
<tr>
<td>Tollbooth Transponders</td>
<td>1 or 2</td>
<td>No</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td><strong>Water and Energy Efficiency (2 points)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stormwater Management</td>
<td>1</td>
<td>Yes</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td>Green Power</td>
<td>1</td>
<td>Yes</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td><strong>Materials and Resources (6 points)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life Cycle Assessment</td>
<td>Required</td>
<td>No</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td>Construction Waste Management</td>
<td>1</td>
<td>Yes</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Material Reduction</td>
<td>1</td>
<td>No</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Regional Materials</td>
<td>1</td>
<td>Yes</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Certified Wood</td>
<td>1</td>
<td>Yes</td>
<td>Moderate</td>
<td>No</td>
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<tr>
<td>Gray Water</td>
<td>1</td>
<td>No</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Cement Replacement</td>
<td>1</td>
<td>No</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td><strong>Innovation in Design (3 points)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Innovation in Design</td>
<td>1 - 3</td>
<td>Yes</td>
<td>Low - High</td>
<td>Maybe</td>
</tr>
</tbody>
</table>

Total points possible is: 25
Points required for certification is: 10
Once the point values were assigned, there were 25 total points possible. LEED™ uses several certification categories based on total points (certified, silver, gold and platinum). Because there are fewer requirements in the bridge rating system than in LEED™, it would be most effective to only use a single target value of points. Any bridge that is equal to or above that value would be considered a certified sustainable bridge. The target value was chosen to be 10. Several of the criteria were site and project specific and should be included in the design if possible, but they are not always feasible, making a higher target value impractical.

There are many combinations of criteria that can create a sustainable design and reach or exceed the target value of 10. Some possible combinations for achieving this target value of 10 are seen in Table 2.

Scenario 1 is a bridge that focuses on innovation. Half of the 10 points come from lane adaptability and innovation in design. The other points come from erosion and sedimentation control, tollbooth transponders, stormwater management, construction waste management and using regional materials.

Scenario 2 is a bridge that redevelops a brownfield. It has HOV lanes and no tollbooths. It uses green power, and reduces the material need by using high performance materials and recycled materials.

Scenario 3 is a bridge on a historic site. This bridge improved access to the site by providing a pedestrian sidewalk. It also avoided placing the footing within the waterway it was crossing. It used certified wood and gray water for its concrete construction, and green power for its energy.
<table>
<thead>
<tr>
<th>Credit</th>
<th>Points Possible</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
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<td><strong>Sustainable Sites (5 points)</strong></td>
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<td>Historic Site Improvements</td>
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<td>Footing and Pier Location</td>
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<td><strong>Traffic Efficiency and Alternative Transportation (9 points)</strong></td>
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<td>HOV Lanes &amp; Transitways</td>
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<td><strong>TOTAL</strong></td>
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</table>

Total points possible is: 25
Points required for certification is: 10
6. Existing Bridges Rated

Three bridges were rated using the sustainable bridge rating system. All three bridges were built recently or are currently under construction in the US. The bridges that were rated are the Leonard P. Zakim Bridge in Boston, Massachusetts, the Arthur J. Ravenel, Jr. Bridge in Charleston, South Carolina, and the Potomac River Bridge connecting Maryland, and Virginia. The Zakim and the Ravenel are both cable-stayed bridges and the Potomac is a multiple span, bascule bridge.

Leonard P. Zakim Bridge – Boston, MA

The 1,432 ft long and 183 ft wide Leonard P. Zakim bridge is the widest cable-stayed bridge in the world. The bridge is made up of 8 lanes with an additional 2 lanes cantilevered off one side. Its assymetrical design makes it both unique and challenging. The 745 ft main span consists of a steel box girder and steel floor beams, while the back spans contain post-tensioned concrete.

Figure 1: Zakim Bridge (Massachusetts Turnpike Authority 2005)

Arthur J. Ravenel, Jr. Bridge – Charleston, SC

When opened in 2005, the Ravenel will be North America’s longest cable-stayed mainspan. Built in a marine, salt-water environment, two 575 ft signature diamond-shaped towers support the 1,546 ft mainspan. The bridge replaces two existing bridges that currently require large amounts of maintenance.

Figure 2: Ravenel Bridge (SC DOT 2005)

Potomac River Bridge – MD, VA

The Potomac River Bridge will replace the 40 year-old Woodrow Wilson Memorial Bridge. The multi-span, reinforced concrete, bascule bridge features 8 lanes of traffic with an additional 2 lanes for HOV or transit. The new bridge will have a clearance of 70 ft, 20 ft higher than the current bridge, meaning that it will open less frequently.

Figure 3: Potomac Bridge Rendering (Woodrow Wilson Bridge Project 2004)
Sustainable Sites:

**Erosion and Sedimentation Control**

**Requirements:**
Design a sediment and erosion control plan, specific to the site that conforms to United States Environmental Protection Agency (EPA) Document No. EPA 832/R-92-005 (September 1992), Storm Water Management for Construction Activities, Chapter 3, OR local erosion and sedimentation control standards and codes, whichever is more stringent. The plan shall meet the following objectives:

- Prevent loss of soil during construction by stormwater runoff and/or wind erosion, including protecting topsoil by stockpiling for reuse.
- Prevent sedimentation of storm sewer or receiving streams.
- Prevent polluting the air with dust and particulate matter.

**Zakim:** Met

**Ravenel:** Met

**Potomac:** Met

**Brownfield Redevelopment**

**Requirements:**
Develop on a site documented as contaminated (by means of an ASTM E1903-97 Phase II Environmental Site Assessment) OR on a site classified as a brownfield by a local, state or federal government agency. Effectively remediate site contamination.

**Zakim:** Not met

**Ravenel:** Not met

**Potomac:** Not met

None of these sites reclaim brownfields.
Historic Site Improvements

Requirements:
Do not demolish any historical bridge as defined by Section 106 of the National Historic Preservation Act. Historic bridges may be moved to an alternative site within 50 miles provided that the site has improved facilities and public access compared to the original site.

If the bridge structure is being built on a historic site or spans over a historic site, improvements shall be made to the facilities and/or access to the site.

Zakim: Met
Ravenel: Met
Potomac: Met

None of these bridges were built on historic sites, or required the demolition of historic bridges.

Footing and Pier Location

Requirements:
Do not place any part of the bridge structure within a waterway. This will avoid potential impacts from construction as well as changes to the water flow.

Zakim: Met
Both towers are placed on land and avoid the Charles River.

Ravenel: Not Met
Both towers footings are situated on drilled shafts within the Cooper River. This was done to minimize the impacts to existing neighborhoods within the city of Charleston.

Potomac: Not Met
Many spans are placed within the Potomac River.
Traffic Efficiency and Alternative Transportation:

**Lane Adaptability**

**Requirements:**
Design the bridge so that two or more travel lanes can be added without strengthening the substructure. Develop preliminary construction plans for the addition of lanes in the future.

Zakim: Not Met

Ravenel: Not Met

Potomac: Not Met

Designing the bridge for future expansion is not a custom that is generally practiced.

**HOV Lanes & Transitways**

**Requirements:**
Provide one or more transitways or one or more travel lanes in each direction of traffic to be used exclusively by at least one of the following HOVs:
- Buses
- 2 or more person carpools

Zakim: Not Met
No HOV lanes or transitways are provided.

Ravenel: Not Met
No HOV lanes or transitways are provided.

Potomac: Met
2 lanes are being built that will either carry HOVs or be converted into transitways. The final plans are still under discussion. These lanes will not open for use until connecting systems are in place on both sides of the Potomac River, and will be used for traffic and incident management during construction.
Bike and Pedestrian Lanes

Requirements:
Provide access and bike lanes and sidewalks for pedestrians. There are 2 points possible, 1 point for providing bike lanes and 1 point for providing sidewalks. A combined bike and pedestrian lane is eligible for 2 points if it is 10 ft or wider.

Zakim: Not Met
No bike or pedestrian lanes are provided.

Ravenel: Met (combined bike and pedestrian lane)
Originally not in the design, a 12 ft combined bike and pedestrian lane was added to the project after citizens requested it through letters, testimony, and even a local bumper sticker campaign.

Potomac: Met (bike and pedestrian lane)
A bike and pedestrian lane is to be built. It is unclear if there will be lines or barriers differentiating between the lanes.

Tollbooth Transponders

Requirements:
There are two points possible:
• 2 points: No tollbooths on the bridge
• 1 point: If there is a toll booth, 50% of the lanes must be exclusive transponder lanes, accepting only cars with electronic transponder payment systems

Zakim: Met (No tollbooths)

Ravenel: Met (No tollbooths)

Potomac: Met (No tollbooths)
Water and Energy Efficiency

Stormwater Management

Requirements:
Construct site stormwater treatment systems designed to remove 80% of the average annual post-development total suspended solids (TSS) and 40% of the average annual post-development total phosphorous (TP) based on the average annual loadings from all storms less than or equal to the 2-year/24-hour storm. Do so by implementing Best Management Practices (BMPs) outlined in Chapter 4, Part 2 (Urban Runoff), of the United States Environmental Protection Agency’s (EPA’s) Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters, January 1993 (Document No. EPA-840-B-92-002) or the local government’s BMP document (whichever is more stringent).

Zakim: Not Met
Stormwater drains directly into the Charles River

Ravenel: Not Met
Stormwater drains directly into the Cooper River

Potomac: Not Met
Originally, there were plans to build stormwater control structures on the bridge surface and channel these waters to appropriate treatment facilities based on land below. These plans, however, have been dismissed because of difficulties coordinating engineering and real estate demands. Placing stormwater reservoir basins beneath the bridge would not blend in with neighborhood profiles and would almost certainly disrupt local community relations.

Revised plans state that the project will not treat water from the new bridge surfaces. Rather, stormwater will fall into the Potomac River from scuppers (drain spouts) built on the bridge.
Green Power

**Requirements:**
Provide at least 50% of the bridge’s electricity (for lighting, etc.) from renewable sources by engaging in at least a two-year renewable energy contract. Renewable sources are as defined by the Center for Resource Solutions (CRS) Green-e products certification requirements.

**Zakim:** Not Met
Most electricity in New England comes from power plants that use nuclear energy and fossil fuels.

**Ravenel:** Not Met
One local utility company does offer green power, but it does not appear to be used for the bridge.

**Potomac:** Not Met
Most electricity in Maryland and Virginia comes from power plants that use nuclear energy and fossil fuels.

Materials and Resources

**Life Cycle Assessment**

**Requirements:**
Perform a Life Cycle Assessment (LCA) on at least three alternatives. It is not required that the lowest life cycle cost option be chosen, only that designers are aware of the potential environmental cost of each option.

**Zakim:** Not Met

**Ravenel:** Not Met

**Potomac:** Not Met

There was no information about whether an LCA was conducted for any of these bridges, but it is likely that it was not. LCA is still a relatively new method and is not currently used on many projects.
Construction Waste Management

Requirements:
Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage at least 50% of construction, demolition and land clearing waste. Calculations can be done by weight or volume, but must be consistent throughout.

Zakim: unknown

Ravenel: unknown

Potomac: unknown

The amount of construction waste that is recycled or salvaged is not generally tracked, and no information was available.

Material Reduction

Requirements:
Reduce the total material required for the bridge by 25%. The reduction can come from structural materials and construction materials, including temporary structures. This reduction may also include materials replaced by recycled material. Calculations can be done by weight or volume, but must be consistent throughout.

Zakim: unknown
The towers have a high performance, Grade-70, but it is unclear if there was a material reduction.

Ravenel: unknown
The footings and towers consist of high performance concrete for seismic design and reinforcement protection, but the strengths were 5000 and 4000 psi respectively (Dunker 2003), so it is unlikely that there was a large reduction in material.

Potomac: unknown
Some of the bridge beams consist of high performance steel, which does reduce the weight of the girders. High performance concrete was used for the footings and some structural elements. It appears that the total material required was reduced, but it is unclear to what extent.

There was no information that indicated that any of the bridges use a significant amount of recycled material.
Regional Materials

Requirements:
Use a minimum of 20% of building materials and products that are manufactured* regionally within a radius of 500 miles.

* Manufacturing refers to the final assembly of components into the building product that is furnished and installed by the tradesmen. For example, if the hardware comes from Dallas, Texas, the lumber from Vancouver, British Columbia, and the joist is assembled in Kent, Washington; then the location of the final assembly is Kent, Washington.

Zakim: unknown
Ravenel: unknown
Potomac: unknown

No information was available for the location of materials used in the construction of these bridges.

Certified Wood

Requirements:
Use a minimum of 50% of wood-based materials and products, certified in accordance with the Forest Stewardship Council’s Principles and Criteria, for wood building components including, but not limited to, structural framing and general dimensional framing, and non-rented temporary construction applications such as bracing, concrete form work and pedestrian barriers.

Zakim: Not met
Ravenel: Not met
Potomac: Not met

It is unlikely that certified wood is currently being used for construction due to its increased cost. However, once the wood was purchased, it could be reused if it was used for temporary construction, which would lower the per use cost.
Gray Water

Requirements:
Use a minimum of 50% gray water in production of ready mixed concrete in accordance with the guidelines and requirements established in ASTM C94.

Zakim: Not Met

Ravenel: Not Met

Potomac: Not Met

It is unlikely that any of these bridges used gray water in their concrete as it is not generally used.

Cement Replacement

Requirements:
Replace a minimum of 20% (by weight) of Portland cement to be used with byproduct cementitious material such as fly ash, silica fume, or ground granulated blast furnace slag (GGBFS).

Zakim: unknown
No concrete mix designs were available.

Ravenel: Met
The mix design for the footings called for replacement of 43% of the Portland cement by fly ash. The superstructure has a replacement of 20% of the Portland cement by fly ash.

Potomac: Met
This requirement was likely met. Fly ash was used for a foam concrete backfill where the bridge meets the land and slag cement was used for some of the applications. The total cement replaces is not known.
Innovation in Design

Innovation in Design

Requirements:
In writing, identify the intent of the proposed innovation credit, the proposed requirement for compliance, the proposed submittals to demonstrate compliance, and the design approach (strategies) that might be used to meet the requirements. There will be one credit awarded per approved innovation, up to 4 credits total.

Zakim:
1 point - The Zakim Bridge has diamond cuts in its surface to let the sun through so that alewives (native fish) can navigate in their spring migration up the Mystic River.

Ravenel:
1 point – The bridge deck used no expansion joints on the backspans, which significantly reduces maintenance and lessens problems due to corrosion.

Potomac:
0 points – The material dredged from the river was used to fill a formerly mined site that has now been turned into farmland. While, reclaiming a formerly unuseable site is sustainable design, dredging can have severe environmental impact, so there is not a significant positive gain.

1 point – Air bubble curtains were developed and used to absorb the harmful pressure waves caused from driving piles, effectively eliminating fish kills from this cause.
Ratings

When the points were totaled, only one bridge, the Potomac Bridge, would definitely achieve a certification rating, provided an LCA had been done on alternatives. The Potomac achieved a minimum 10 points without the unknown factors and up to 13 points if all the unknown criteria were met.

The Ravenal may meet certification if 2 out of 3 of the unknown criteria are met (construction waste management, material reduction, and regional materials). Alternatively, certification could be achieved by converting lanes to HOV lanes or by using green power in combination with one of the unknown criteria.

The Zakim is not likely to meet certification unless additional lanes are added. Since this bridge is already built, it is not likely that any changes would be made.

<table>
<thead>
<tr>
<th>Credit</th>
<th>Points Possible</th>
<th>Zakim</th>
<th>Ravenel</th>
<th>Potomac</th>
</tr>
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<tbody>
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<td><strong>Sustainable Sites (5 points)</strong></td>
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<td></td>
</tr>
<tr>
<td>Erosion and Sedimentation Control</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Brownfield Redevelopment</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historic Site Improvements</td>
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<td>1</td>
</tr>
<tr>
<td>Footing and Pier Location</td>
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<tr>
<td><strong>Traffic Efficiency and Alternative Transportation (9 points)</strong></td>
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<td>Lane Adaptability</td>
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<td>HOV Lanes &amp; Transitways</td>
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<td><strong>Water and Energy Efficiency (2 points)</strong></td>
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<td>Gray Water</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement Replacement</td>
<td>1</td>
<td>?</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Innovation in Design (3 points)</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Innovation in Design</td>
<td>1 - 3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>25</td>
<td>6 - 10</td>
<td>8 - 11</td>
<td>10 - 13</td>
</tr>
</tbody>
</table>
7. Evaluation

Overall, the rating system addresses several factors important in sustainable design, from site selection, to geometric design, to materials. The rating system is a basis for sustainable design, and can be expanded in the future to include other criteria when applicable, provided that they meet the goals of achieving sustainability.

It was surprising that 2 out of 3 of the bridges evaluated met or could easily meet the target value of 10 out of 25 points. Perhaps this target value should be increased or additional certification levels could be added (i.e. 10 point for certification, 15 points for gold rating, and 20 points for platinum rating). The goal of the rating system is to encourage growth in sustainable design, not simply to give certification to bridges that are being designed under current practices. Setting a higher target value would require designers to attain some of the less standard design criteria, such as green power, and certified wood.

In looking at the rating criteria, it seems that there are multiple criteria pertaining to concrete, and none directly pertaining only to steel. This may seem like the rating system favors concrete over steel, however, even steel bridges use concrete for components like footing, piers, and abutments. Therefore, steel bridges will be able to achieve the points pertaining to concrete.

8. Conclusions

This thesis has developed a rating system for sustainable bridge design, which considers the environmental and socio-cultural effects bridges have in addition to their economic effects. For a truly sustainable design, there needs to be a balance of all three. The rating system evaluates bridges based on measurable criteria and, and assigns a point value based on “sustainability”.

This rating system will have a large impact on the way bridges are designed and the environmental impacts they require. It gives designers the tools to consider environmental effects through all the stages of bridge design and construction. By using a “whole-life” approach, sustainable bridge design will be successful and effective.

The next step in implementation is to submit this thesis to the Federal Highway Administration. Ideally, it would become part of their specifications for bridge projects.

It is the responsibility of humanity to ensure that resources are available for the next generation, and for many generations to come. Sustainable design is responsible design, and the duty of design falls on engineers. It is engineers that have, and will continue to advocate and practice sustainable design to protect our vital resources.
References


