Sustainable Structures for the Bridge Engineer

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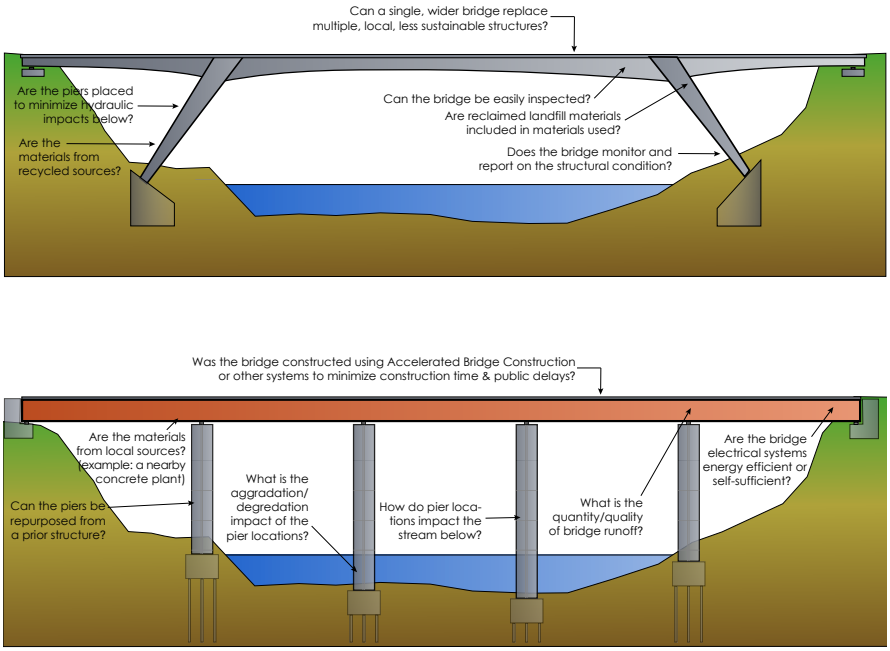
Many fellow bridge engineers, when faced with the term "Sustainable Bridge", conjure up images in their minds of picturesque glued-laminated structures blending in harmoniously with their surroundings deep in a national park. Or, their imagery may stop at a vegetated wildlife crossing over a perilous section of interstate. Notably, both of these images would seem to have very little applicability to the real world problems faced by either the bridge owner or bridge professional, and would be quickly dismissed as something unpractical or of limited usefulness.

In reality, such images and the basic assumptions behind them are off the mark. To reframe the discussion, sustainable design is commonly defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Extrapolating from this basic definition, a sustainable engineering project such as a bridge can therefore be defined as one that is conceived, designed, constructed, operated, maintained, and eventually put out of service in such a fashion that these activities demand as little as possible from the natural, material and energy resources of the surrounding supporting community.

So, in practice, sustainable bridge design is not about strictly environmental concerns, or only about energy conservation. Instead, it is a more holistic – top to bottom review and evaluation of a bridge project's merit and compatibility with the indigenous human and wildlife populations on both the micro and macro scale. As such, it has the potential to be a useful tool to quantify and determine the true scale of even indirect or unintended deterioration done to our environment, society and the community at large.



Sustainability Considerations for Two River Crossings

Envision sustainable bridge design something like the following: given a typical local collector crossing over a waterway, a partial list of the responsibilities necessary to complete this task might look like those listed in *Table 1*.

Each of the items in *Table 1* is referred to as a "hat" because an engineer (often on smaller structures, a single engineer) dons the hat somewhat independently from others during the course of a design. For example, the engineer performing the highway design typically dons his/her highway design hat to lay out the geometry for a new structure, then dons a different structural engineering hat to ensure that the bridge is adequately reinforced. Each of the hats can be thought of as occurring at finite, discrete moments during the planning, design, and construction phases of this sample project.

Table 1: Typical Bridge Design "Hats"

Task	Phase
Feasibility Study	Planning
Siting	Planning
Type Study	Planning
Highway/Geometric Design	Design
Hydraulic Analysis	Design
Structural Design	Design
Cost Estimate	Design
Materials Testing	Construction
Shop Drawing Review	Construction

But when held against our definition of sustainable design, this analogy breaks down. This is because sustainable design is not an individual task to be performed at a discrete point in the design process. In order to produce a project that is truly sustainable throughout the structure's life, *each* of the tasks need to be considered from a sustainability standpoint. For instance, when locating the bridge, is it better to place it within wetlands or in the dry? When performing hydraulic analysis, how will the constriction and reduced hydraulic opening impact the upstream and downstream flows and ecosystems? During the construction phase, where did the materials used in the structure come from, and are they being used to their greatest effect?

In order to ever hope to meet the burden of our definition of sustainable design, what is required is not a new hat, but a new pair of glasses to look with an additional perspective at every step in a project's progress. Or, in order to deliver a truly sustainable bridge, sustainable goals need to be considered and accounted for throughout almost every phase of the planning, design, construction and maintenance process.

Quantification

So, with a useful definition applied to the concept, the next logical question becomes: how is a sustainable bridge project's goals measured and quantified?

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Table 2: LEED Design Goals vs. Sustainable Bridges

LEED Design Goals	Equivalent Bridge Design Goal
Sustainable Sites	Sustainable Sites
Water Efficiency	Water Use and Quality
Energy and Atmosphere	Energy and Transportation
Materials and Resources	Materials and Resources
Indoor Environmental Quality	N/A

In the United States, there is currently no national standard for the measurement or ranking of sustainable bridges like the U.S. Green Building Council's (USGBC) benchmark LEED® standard for buildings. The USGBC describes its program as follows: "The LEED (Leadership in Energy and Environmental Design) Green Building Rating System is the nationally accepted benchmark for the design, construction, and operation of high performance green buildings". The system has become the leading national baseline standard for quantifying how sustainable a building project, a school, or now, even a neighborhood planning project is.

At first glance, the system would seem to have no bearing on a similar metric for sustainable bridge design. However, by looking at the LEED standard, it may be possible to extract some useful metrics to help in the measurement of bridges.

At its core, the LEED guidelines break down any potential sustainable building project into one of 5 overarching categories. For comparison's sake, each of these building categories will be matched with a comparable bridge design metric, as shown in *Table 2*. Out of these goals, only the LEED category of Indoor Environmental Quality, which is concerned with indoor pollutants, seems to have no corresponding equal in a sustainable bridge metric.

Sustainable Sites

The hallmark of a sustainable site is – is this the right location for this structure? Questions posed in a possible sustainable site category could include the following considerations:

- Does the site employ available best practices in sedimentation and erosion control?
- Does the bridge connect two well-established existing developments, or is it a bridge to "nowhere"?
- Does the proposed structure add to the economic and social value of the two bodies it connects?
- Does the bridge disturb a greenfield, wetland or farmland?
- Does the design consider or was the bridge constructed in such a fashion as to minimize delays to the general public?
- Does the bridge replace or improve an existing structure or is it a new structure?
- Are footings and piers required, and how does their placement impact the surrounding environment?
- Can a bridge in one location replace several smaller, possibly less functional bridges in disparate locations?

Water Use and Quality

A water use and quality category is used to investigate the quality and quantity of water used in construction and that which runs off the structure after its installation. Consider the following:

- For water crossings, how does the proposed hydraulic opening impact the flood performance upstream and downstream?
- Was non-potable water used during the construction process? How much?
- What systems are in place to ensure that runoff from the bridge is minimized (grass swales along the curb, etc.)?
- What systems are in place to ensure runoff from the structure is of high quality?
- Where is the runoff from the bridge discharged?

Energy and Transportation

It has been calculated that transportation represents 10 percent of the world's gross domestic product, and is responsible for 22 percent of global energy consumption and 25 percent of fossil fuel use across the world. The proposed purpose of an energy and transportation category is to ensure that the structure is designed and constructed to minimize the energy and transportation needs of the surrounding community. Questions to pose could include

- Is the bridge equipped with remote health monitoring sensors to reduce the need or frequency of hands-on inspections?
- Does the bridge easily facilitate hands-on inspection of its individual components when required?
- Does this bridge installation reduce the average miles traveled between the neighborhoods it connects?
- Was the bridge constructed using Accelerated Bridge Technologies or other techniques to minimize construction activity and energy consumption?
- Can on site generation sustain the bridge's own electrical needs?
- Are the bridge electrical components energy efficient?
- Is the bridge equipped with a High Occupancy Vehicle/(High Efficiency Vehicle) lane?
- For toll roads or signature structures, is the bridge equipped with automated toll taking/changeable message signs/traffic queing features?
- Does the bridge include sidewalks and/or bicycle lanes?
- Does the bridge include facilities to encourage mass transit?

Materials and Resources

A material and resource category ensures that the choice in bridge materials is appropriate for the site and the future maintenance and recycling of the structure. Sustainable Material and Resource questions include:

- Are recycled materials used in the structure?
- Can the materials used in the structure be recycled?
- If rehabilitated, are the materials from the old structure reused in the new?
- If rehabilitated, how much of the original structure is utilized in the new design (abutment stems, piers, etc)?
- Are materials regionally available or brought in from long distances?
- Are new materials or processes utilized that reduce the overall quantity demands for the structure?
- Are otherwise landfilled materials used in the bridge construction (i.e. – fly ash or slag in concrete mixes)?
- Is the bridge designed with a complete Life Cycle Analysis in place?

Potential Benefits

After sustainable bridges have been suitably defined and quantified, the inevitable question then becomes: what are the tangible benefits for investing the extra layer of effort and resources into such a project?

Hard evidence for the benefits of this type of bridge design is an area that requires more real world examples, and both academic and field studies as have been done previously for buildings. However, from the above metrics, a list of proposed benefits for this type of design could include the following:

- Bridges that utilize fewer raw materials on the jobsite
- Bridges that utilize less time and energy to construct
- Bridges that funnel materials away from overcrowded landfills.
- Bridges that meet their own electrical needs
- Bridges that help deal with the coming needs of 21st century travel of faster and more efficient transportation
- Bridges that encourage alternate modes of transportation
- Further funneling of federal research dollars into leading edge bridge design and materials
- Bridges that produce fewer upstream and downstream negative impacts to both the natural and developed communities
- Bridges that due to their certification could streamline the permitting process
- Bridges that are able to monitor their own health and alert owners to critical conditions
- Bridges that better enhance the social and economic communities and tie established neighborhoods together
- Bridges that are better planned and thought out with engineering judgment that can ultimately better serve the public

The above lists deals only with the hard benefits. Looking at the soft side, research into sustainable buildings seems to indicate that people are more attracted to and want to be inside these buildings, and will pay a premium to do so. Similar effects could be seen with sustainable bridge projects in relation to the various funding sources, and the public and governmental influences behind them.

Current State of Sustainable Bridges in the United States

As has been mentioned, there currently is no national standard for quantifying sustainable bridges in the Unites States. Therefore, the number of bridges conceived and branded with "sustainable" labels as of the time of this writing is minimal.

These two facts are interrelated. With no reliable national standard or best practices established, it is hard for an outsider to distinguish between a conventional and sustainable design and no way to elevate one project's features over another's. Of the bridges that have been built, it is hard to distinguish many of these bridge's claims to the label of "sustainable" (or the more nebulous label of "green") as the lack of an agreed upon standard allows even the installation of just one pertinent feature access to the sustainable title for the entire crossing.

Sustainable bridge design is a modern day topic that requires more academic study, modeling, testing and thought to move forward in a meaningful way. This field of research should be applied to supplying hard data to the following currently unanswered, but important and pertinent, questions:

- What is the proper weighting of a proposed sustainable bridge metric?
- What are the performance benefits or detriments of a sustainable bridge versus a traditional one?
- What is the cost premium of a sustainable bridge/sustainable bridge component? What are the economic incentives?
- What new or proposed materials are available to contribute gainfully to a sustainable bridge product or component?
- What impact do these metrics have on the actual sustainability of a bridge crossing?

A national standard could also serve to regulate the current "wild west" feel of the sustainable materials marketplace. Currently, with no oversight, a new material vendor or process can apply labels at will, with little to no tangible benefits to back it up. If a bridge owner or designer knows that a given product has a direct impact on a given sustainable metric, the material vendor has a much more legitimate claim on these types of labels.

Conclusion

It is time for the more insular world of bridge engineering and maintenance to join the growing numbers of professionals from all trades that are realizing the tremendous potential of sustainable design. Not to be confined just to the building and planning industries or the "green fringe," bridge professionals involved with all aspects of the typical bridge lifecycle can benefit from a national, standardized set of sustainable bridge metrics. Further study and research of both national and international standards will be required to solidly establish the end value and proper weighting of any standard set of proposed metrics. In the meantime, the metrics proposed in this paper and found elsewhere can be used as a launching point for potential pilot projects to facilitate further study in this emerging transportation field.▪

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