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# Developing green bridge rating system using Simos' procedure



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## KEYWORDS

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**Abstract** Sustainable development principles have been implemented in various sectors including construction. Proper development and operation of infrastructure projects, such as bridges and highways, can contribute significantly to the mission of sustainable development. In this respect, there is little existing work on appropriate methods to assess the sustainability performance of bridge projects. This paper introduces a key-list of gathered important criteria that affect the sustainability of bridge projects. Various construction industry standards have been reviewed in order to decide the criteria that influence sustainability of bridge projects. The initial list of criteria has been identified by unstructured interviews. Then, structured interviews and questionnaire survey have been conducted to identify the final list that is deemed important in rating green bridges. Various construction industry standards have been reviewed to decide on the criteria that influence sustainability of bridge projects. Final criteria results from this paper are used to develop a green bridge rating system to achieve sustainable development. Degree of importance and weights of these criteria are determined using Simos' procedure. Five classes of bridges are proposed to judge their status with respect to sustainability, with these being Non-Green, Certified, Green, total Green, and Evergreen.

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## Introduction

Various construction standards have been developed to examine the highway bridge projects' sustainability from

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different perspectives. These standards include Environmental Protection Agency (EPA) [1], American Association of State Highway and Transportation Officials (AASHTO) [2], Federal Highway Administration (FHWA) [3], and Leadership in energy and environmental design (LEED) [4]. World Commission on Environment and Development (WCED) [5] defined sustainability development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs". No doubt that bridge projects have been given particular importance as they have a great impact on the economy, social aspects and the environment. The proper development and operation of bridge construction



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projects can contribute significantly to the mission of sustainable development. Bridge construction projects include a wide range of construction works such as highway bridges, railway bridges, and others. Bridge constructions play an essential role in economic and social developments. It is estimated that a one percent increase in infrastructure stock is associated with a one percent increase in Gross Domestic Product GDP [6]. Easterly and Rebelo [7] reported that investment in highway bridges and communication has a positive effect on the economic growth. Combustion of fossil fuels leads to greenhouse gas emissions. Overuse of water for irrigation (which accounts for about 90% of water withdrawal in most low-income countries) damages soil and severely restricts water availability for both industry and households [8]. Some infrastructure investments, especially bridge construction, can put unspoiled natural resources at risk and threaten indigenous communities. Therefore, in line with the promotion of sustainable development worldwide [8–9], it is of utmost importance to find ways for gaining better sustainability performance while executing bridges which will remain extensive in the near future. While LEED is the building industry benchmark in sustainability, there are other rating systems implemented and in various stages of development. The Green Guide for Healthcare [10] was created in 2003 for hospitals and is currently in the process of being incorporated into LEED [4]. Green roads [11] is a rating system focusing on sustainable transportation practices. Examples for different standards are GreenLites [12] (Leadership in Transportation and Environmental Sustainability), and Stantec's Green Guide [13]. A positive impact of green bridge projects is that the productivity of workers increases. In addition, green bridge projects make working environment more attractive, comfortable, and provide healthier conditions for its constructors and users. This is done by achieving the aspects of sustainability criteria. Since working conditions are improved, workers are healthier and therefore use less sick days. This can result in large financial benefits for the employer [14]. Bridges with lower life cycle costs will tend to have lower environmental impacts. In other words, the least expensive bridge alternative is also likely to have the least associated emissions and embodied energy. The key is to consider the total costs for design, construction, use, maintenance, demolition, and salvage, not merely initial construction cost. Many recycled materials, including steel, pozzolan cements, wearing surface aggregates, and construction waste, are cost competitive in terms of both initial cost and life cycle cost with virgin alternatives. There is no significant difference in average construction costs for green buildings as compared to non-green buildings [15]. Similar conclusion was drawn when investigating the costs associated with the thirty-three LEED certified municipal buildings built by the state of California [14]. The Federal GSA decided to fund its green building mandate by allocating a 2.5% construction budget increase. Whichever estimate is used, the sources agree that the initial investment in green building is rewarded by many times over the life of the structures. This is due to lower life cycle costs in the form of decreased energy, water, and waste use [14]. This indicates that the proposed green bridge standard does not increase construction costs and will certainly reduce life cycle costs and maintenance costs. This paper proposes a methodology for developing a rating system for green bridges. The research is developed considering the following procedure: (1) creating an initial list that contains the most important criteria to build

up green bridge rating system, (2) developing the final list of criteria using statistical analysis descriptive tests according to the degree of importance of each criterion, and (3) using Simos' approach to determine the weights of each criterion.

### Research methodology

In an effort to develop a rating system for green bridges, a three-phase research methodology has been followed and described hereinafter.

- *Literature Review Phase:* This phase was started prior to the commencement of the questionnaire survey. It was devoted for reviewing the literature for identifying the criteria affecting bridge sustainability.
- *Unstructured Interviews Phase:* In order to corroborate the findings and views of the earlier studies, several unstructured interviews were individually conducted with nine experts in bridge construction projects. The participating experts were requested to identify and enumerate the criteria affecting green bridges from their own point of view in a separate list. During these interviews, the participating experts were only asked general questions regarding the affecting criteria. In all cases, notes were taken without any influence or intervention. Next, a combined list was prepared from the participant's answers.
- *Questionnaire Survey Phase:* Questionnaire survey was used to finalize the list of criteria essential for constructing green bridge rating system for bridge projects. It consists of three main sections; Section one includes the respondent personal data, while section two is the principal component of the questionnaire. The list of criteria associated versus levels of importance is included. Section three has a list for any extra information that can be added by the expert. The methodology of eliciting expert response regarding his/her assessment of the degree of importance associated with each criterion is performed based on a scale that ranges from "1" to "10" which corresponds to "Very Low Importance" to "Very High Importance".

### Identification of criteria

Several literature efforts have been reviewed to identify the list of criteria that can be considered in the rating system of green bridges [4,15–18]. Subsequently, several structured and unstructured interviews with experts in bridge construction have been conducted. The initial list contains twenty-seven criteria that belong to five categories: Project Requirements, Environment and Water Category, Access and Equity Category, Construction Activities Category, Materials and Resources Category. This is listed in Table 1.

### Questionnaire survey

The questionnaire survey contains twenty-seven criteria that have been collected from the literature and reviewed by nine experts via un-structured interviews. Experts have responded to the survey to satisfy the number of the designed sample size to select the most important criteria. Samples of construction, consultants and employer representative companies have been

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