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MTI MINETA TRANSPORTATION INSTITUTE

Evaluation of Sustainability Determinants to Develop a Sustainability Rating System for California Infrastructure Construction Projects

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16. Abstract:

This study evaluates the important sustainability determinants that affect factors' success in meeting their sustainability goals when conducting infrastructure construction projects in California. The study implemented the online survey method to evaluate the sustainability characteristics that infrastructure industry professionals currently are aware of under the current situation in California. A data set of 25 validated survey responses is used for statistical data analysis using analysis of variable, Kruskal-Wallis tests, and two sample t-tests. The analysis results showed that the median response values for the six major sustainability categories do not show any significant difference. The results also showed that no statistically significant difference in the mean response values can be found from the six major sustainability categories considered. Based on the pairwise comparison results, only the other category showed difference with water- and energy-related categories. However, mean ranks among the factors under each category are useful in prioritizing the importance of the factors considered, which will be useful for the successful implementation of sustainability in infrastructure construction projects in California. These results are meaningful for legislators and transportation agencies because they provide insights about the sustainability criteria relevant to infrastructure construction projects for better informed decisions about how to meet the projects' sustainability goals.

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Executive Summary

The goal of this project is to provide insights about the sustainability criteria relevant to California infrastructure construction projects so that transportation agencies can be better informed about how to meet the projects' sustainability goals. The online survey for transportation planners, engineers, construction managers, and/or policymakers is designed and implemented to determine the important sustainability determinants that affect factors' success in meeting their sustainability goals when conducting infrastructure construction projects in California. This project is limited to Californian infrastructure construction projects, which may confine the outcomes to lead a general adaptation by other state transportation authorities, but it is meaningful for a better understanding of the contemporary issues and demands related to California infrastructure construction projects and their ongoing sustainability efforts.

This study evaluates important sustainability determinants that affect factors' success in meeting their sustainability goals when conducting infrastructure construction projects in California. The authors analyzed the factors used in existing sustainability rating systems in the nation and identified the common factors. This study grouped the factors into six major categories such as site-related category, water- and wastewater-related category, energy-related category, materials- and resources-related category, environmental-related category, and other category. The other category includes factors that do not directly support the category. The study implemented the online survey method in October to December 2021 to evaluate the sustainability characteristics that infrastructure industry professionals currently are aware of under the current situation in California. A data set of 25 validated survey responses out of 59 surveys collected is used for statistical data analysis (Analysis of Variable, Kruskal-Wallis tests, and two sample t-tests).

The analysis results showed that the median response values for the six major sustainability categories do not show any significant difference. The results also showed that no statistically significant difference in the mean response values can be found from the six major sustainability categories considered. Based on the pairwise comparison results, only the other category showed difference with water- and energy-related categories. However, mean ranks among the factors under each category are useful in prioritizing the importance of the factors considered, which can be useful for the successful implementation of sustainability in infrastructure construction projects in California. The study findings are meaningful for legislators and transportation agencies because they provide insights about the sustainability criteria relevant to infrastructure construction projects for better informed decisions about how to meet the projects' sustainability goals. Therefore, the study can be used as a steppingstone for deciding the important sustainability determinants when implementing the sustainability strategies in infrastructure construction projects.

1. Introduction

1.1 Problem Statement and Motivation

The transportation industry significantly contributes to greenhouse gas emissions, generating an average of 6 billion metric tons of carbon dioxide each year between 1990 and 2016. Carbon dioxide (CO_2) from fossil fuel combustion is responsible for almost all greenhouse gas (GHG) emissions from transportation sources. The transportation industry was the source of 29% percent of all U.S. energy consumption in 2017. For context, U.S. energy consumption was about 17% of the world's total energy consumption in 2016 (EIA 2018). It is evident that the transportation industry has a significant impact on the environment and the consumption of natural resources. Transportation systems have a considerable correlation with quality of life. For example, transportation systems provide transportation for the distribution of goods and services, access to health care and education, and personal mobility. Therefore, the implementation of sustainable transportation systems is necessary for present and future benefits.

Transportation is second among the five sectors with the highest energy consumption in the United States; the other sectors are electric power, industrial, residential, and commercial (EIA 2018). Reducing energy use for transportation requires immediate action if we hope to ensure climate resilience and a livable future for future generations. There is an obligation to ensure the distribution of resources for all people. The obligation refers to the right of all people to equitable shares of materials, land, energy, water, and environmental quality. Sustainable development provides for the needs of the present without compromising resources for future generations. One of the solutions for consuming less energy could be sustainable development in primary energy consumption sectors with the aim of limiting the consumption p^of natural resources such that present needs are met while ensuring future generations' access to adequate reserves (WCED 1987). Black (2010) identified four issues to be resolved to maintain sustainable development in transportation systems, including consumption of limited resources, injuries caused by traffic congestion, heavy traffic congestion, and damage to the environment. Because of the profound impact that U.S. highways have on sustainable transportation efforts, it is essential to consider the perspective of the regulatory body governing highway projects. The Federal Highway Administration (FHWA) defines sustainability in highways as giving equal weight to environmental, economic, and social values. This definition means that sustainable highways are supposed to aim for safety, mobility, environmental protection, livability, asset management, and effective cost management in their life cycle (FHWA 2018). Because the world's limited sources need urgent care, the construction industry has become more interested in sustainable development (Reeder 2010).

Many rating systems for infrastructure and transportation projects have been developed using point-based systems; these are comparable to the LEED system of the United States Green Building Council for building construction (USGBC 2018). Such developments are ongoing. However, the use of these sustainability rating systems in infrastructure projects, especially in the transportation sector, is not as common as in building design and construction. Simpson (2013, 2014) compiled and compared ten rating systems to develop a framework for Colorado DOT, South Dakota DOT, Utah DOT, and Wyoming DOT. While the methods and criteria of these rating systems share some commonalities, they also differ from one another in certain ways. Thus, it might be difficult for decision-makers to choose the best sustainability rating system for evaluating their project. Thus, thorough and comprehensive research in this area is needed, as it helps project teams make reliable decisions about the best sustainability assessment tools for a given infrastructure project. Therefore, this project aims to fill a gap in the literature by conducting quantitative analysis, identifying the most appropriate determinants of sustainability for California's infrastructure construction projects so that transportation agencies, professionals, and federal and local governments have the ability to make more effective and efficient decisions about which sustainability assessment tools are a good fit for their projects.

2. Research Objectives and Methodology

2.1 Research Objectives and Scope

The objective of this project is to develop a framework to be used as a sustainability rating tool for California infrastructure construction projects by conducting quantitative analysis using a survey technique with infrastructure industry professionals. The online survey for transportation planners, engineers, construction managers, and/or policymakers is designed and implemented to determine the important sustainability determinants that affect factors' success in meeting their sustainability goals when conducting infrastructure construction projects in California. The goal of this project is to provide insights about the sustainability criteria relevant to infrastructure construction projects so that transportation agencies can be better informed about how to meet the projects' sustainability goals.

This project is limited to Californian infrastructure construction projects, which may confine the outcomes to lead a general adaptation by other state transportation authorities, but it is meaningful for a better understanding of the contemporary issues and demands related to California infrastructure construction projects and their ongoing sustainability efforts. This project identifies main issues in the current understanding of transportation sustainability rating tools from the perspectives of infrastructure construction project professionals. By developing a transportation sustainability rating system, this project can shape transportation project decisions towards success in project sustainability goals, change the mindset of project participants, and aid in developing appropriate strategies as well as promoting better management of California's infrastructure construction projects. The results can have a great impact on the benefit/cost dynamics in the transportation industry and on California's economy.

2.2 Research Methodology

This project aims to determine the important factors affecting California infrastructure construction projects' success in meeting their sustainability goals. To that end, the members of the research team created an online survey to evaluate the sustainability characteristics that infrastructure industry professionals currently are aware of under the current situation. The authors analyzed the factors used in existing sustainability rating systems in the nation and identified the common factors among them. The factors found from the literature review were used in the survey. This study grouped the factors into six major categories such as site-related category, water- and wastewater-related category, energy-related category, materials- and resources-related category, environmental-related category, and other category. The factors that directly support the category are assigned into each category so that industry professionals can answer the online survey that evaluates the importance of sustainability goals for infrastructure construction projects in California based on their experiences. In addition, we developed an efficient survey approach to generate enough variation in attributes to obtain statistically significant parameter estimates. The research process also involved training a student assistant, who collected reliable survey data while avoiding biased responses.

Statistical methods are used to conduct the quantitative analysis of 7-point Likert scale data for six major sustainability categories and their related factors. First, descriptive statistics such as the means, medians, and standard deviations were calculated to describe the data distributions. Second, to verify the assumption of normality before testing hypotheses, normality was tested using the Anderson-Darling test for each of the six major sustainable categories and criteria. If the p-value obtained from the normality test is greater than the significance level of $\alpha = 0.05$, then the null hypothesis that the data follow a normal distribution is not rejected but can be confirmed by the normality graph that shows the data points are relatively close to the fitted normal distribution line. Third, Bartlett's test of homogeneity of variances is conducted to identify equal variances of interval-level dependent variables among the six major sustainable categories that are the independent variables. The equal variance tests examine the null hypothesis of no difference in variances between the categories. Fourth, based on the status of parametric assumptions such as normal distribution and equal variance, the Kruskal-Wallis test was conducted to determine whether the medians of the six major sustainable categories differ. The Kruskal-Wallis statistic helps us to test the hypothesis that all population medians are equal among categories. If the null hypothesis of equality of population medians is rejected, then we compared the individual categories using a pair-wise comparison. As an alternative test, the one-way Analysis of Variance (ANOVA) was also conducted because the survey data have 25 points for six major categories, which meets the sample size guideline for the one-way ANOVA. One-way ANOVA also performs very well with skewed and non-normal distributions, and it has more power than non-parameter tests. Minitab 20, the latest version of one of the statistical software packages, was used for statistical analysis (Minitab 2020).

3. Data Collection

3.1 Survey Design for Exploring Infrastructure Sustainability Systems

The project team designed an online survey questionnaire based on the information gathered from the literature. We used the Qualtrics program, which is a simple and secure web-based survey tool used to conduct survey research, evaluations, and data collection. Qualtrics is compliant with Health Insurance Portability and Accountability Act (HIPAA) and the Family Education Rights and Privacy Act (FERPA), and it achieves Americans with Disabilities Act (ADA) compliance. The initial survey was evaluated by a panel of two experts, each of whom has significant experience in sustainability rating tools for California transportation construction projects. The online survey was approved by the California State University Long Beach's Institutional Research Board.

The survey consists of four major components: background information, insights into existing sustainability rating tools and their applicability in California infrastructure construction projects, characteristics and importance levels for six major sustainability categories and their related factors, and open questions on performance measures and improvements. The first component of the survey begins with the number of years that the respondents worked for infrastructure construction projects in California, followed by the current roles and/or jobs that the respondents currently hold (including engineer/designer, construction manager, inspector, or member of a government agency), and the number of projects for which they used any sustainability rating system available in California.

The second component of the survey asked respondents for the name(s) of the sustainability rating system(s) that their organizations or companies use (past or present) for infrastructure construction projects, the purpose for using the sustainability rating system(s) for infrastructure construction projects, and whether the California Department of Transportation (DOT) needs to develop its own sustainability rating system as a standalone system for infrastructure construction projects in California. The questions in this component also asked the respondents for the assessment method for the development of a sustainability rating system for California infrastructure construction projects, the stage at which the development of a sustainability rating system for California infrastructure construction projects is most beneficial, the measurement method for the development of a sustainability rating system for California infrastructure construction projects, and whether the California DOT needs to incorporate innovation in design and regional priority into its own sustainability rating systems as a standalone system for infrastructure construction projects in California comparable to USGBC's LEED system. The respondents were also asked to recommend at least three rating systems that are most beneficial for the development of a sustainability rating system for California infrastructure construction projects from the existing ten rating systems. The systems listed include Building Environmentally and Economically Sustainable Transportation Infrastructure-Highways (BE2ST in-Highways), Envision®, Green Guide for Roads, Green Leadership in Transportation Environmental Sustainability (GreenLITES), GreenPave, The Greenroads Rating System (Greenroads), Illinois-Livable and

Sustainable Transportation (I-LAST), Infrastructure Voluntary Evaluation Sustainability Tool (INVEST), Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm (CEEQUAL), and Sustainable Transportation Analysis and Rating System (STARS).

In the third component of the survey, the respondents were asked to rate six major sustainability-related categories and their related factors on a 7-point Likert scale to effectively analyze their opinions on how important each category and factor is to sustainable infrastructure construction projects in California. The six major categories include site-related category, water- and wastewater-related category, energy-related category, materials- and resources-related category, environmental-related category, and other category. The possible answers are strongly disagree (1), disagree (2), somewhat disagree (3), neither agree nor disagree (4), somewhat agree (5), agree (6), and strongly agree (7). Strongly disagree means that that criterion is of the least importance to the respondent. Strongly agree shows that the respondent thinks that that factor is of the greatest importance and its effect on sustainability is more considerable than the other factors'. The open-ended questions are the last component of the survey. The respondents were asked to answer two open-ended questions soliciting their opinions about what measurements are needed when developing the sustainability rating system and what improvements are needed for infrastructure construction projects in California.

3.2 Data Collected

The writers of this report collected online survey data from October to December 2021. The total number of individuals who attempted the survey was 59 people. Of those 59 surveys, some respondents did not actually complete the survey: the data show that they started the survey but did not finish it, resulting in a progress rate of less than 100%. These incomplete survey data were eliminated from the data analysis. Of those 59 individuals, 25 respondents' surveys (42.4%) have validity indicated as "True" (i.e., the survey was completed), and only their responses were used for the data analysis.

4. Data Analysis and Findings

4.1 Analysis of Existing Experiences of Infrastructure Sustainability Systems

To understand the respondents' background and prior experiences with existing infrastructure sustainability systems, we asked the respondents to report the number of years spent working in infrastructure construction projects. Respondents possess an average experience of 17.96 years (SD = 9.95) with a median of 18 years. Figure 1 shows the distribution of the current roles and/or jobs that respondents hold. The respondents are classified as engineers/designers, construction managers, and government agency employees (55.6%, 13.9%, and 30.6%, respectively). The average number of projects for which they used any sustainability rating systems available in the industry is 8.68 projects (SD = 3.95) with a median of 3 years.

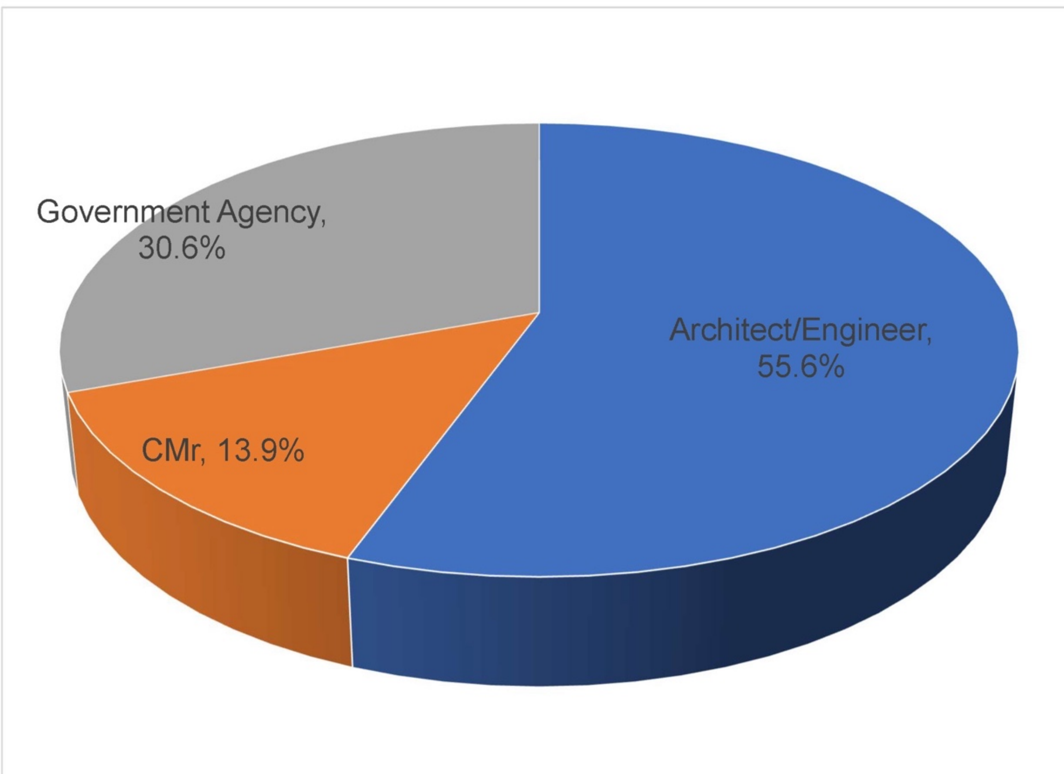

Figure 1. Distribution of Respondents' Roles

To gain better insight into the respondents' perceptions of existing infrastructure sustainability systems, we asked respondents to answer a series of seven questions. First, they were asked to answer the name(s) of the sustainability rating system(s) that their organizations or companies were using or had used for infrastructure construction projects. The sustainability rating system examples provided to the respondents include Infrastructure Voluntary Evaluation Sustainability

Tool (INVEST), Green Leadership in Transportation Environmental Sustainability (GreenLITES), Illinois-Livable and Sustainable Transportation (I-LAST), The Greenroads Rating System (Greenroads), Envision®, Building Environmentally and Economically Sustainable Transportation Infrastructure-Highways (BE2ST in-Highways), GreenPave, Green Guide for Roads, Sustainable Transportation Analysis and Rating System (STARS), and Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm (CEEQUAL). As shown in Figure 2, the respondents had used Envision® the most (77.8%), followed by other frameworks and INVEST (3.7% and 18.5%, respectively). Four of 25 respondents had used USGBC's LEED rating system, and one of them had adopted an internal policy to use "low impact" concrete and asphalt having 30% fewer emissions.

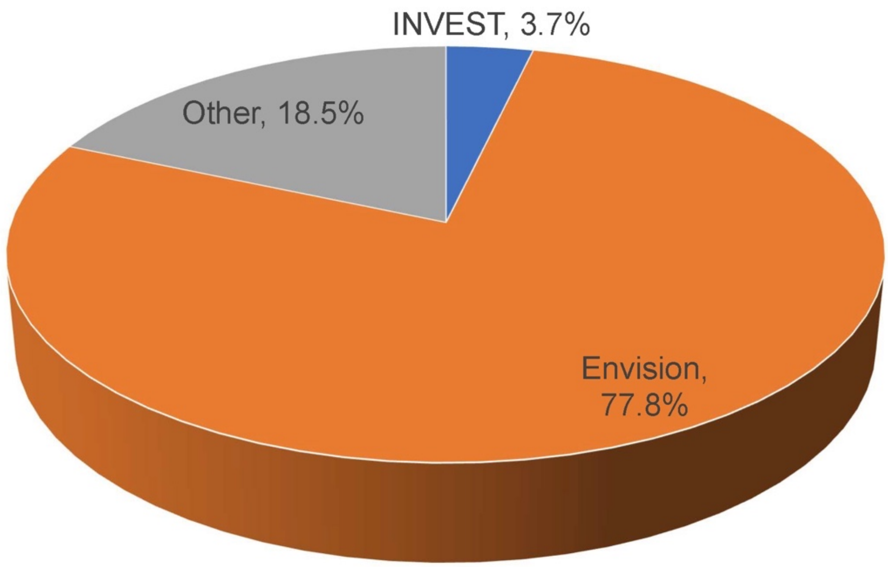

Figure 2. Distribution of Previously Used Rating Systems

Second, the respondents considered "meeting the commitment of the organization's sustainability goals" to be the major purpose for using sustainability rating systems for California infrastructure construction projects, as shown in Figure 3. The percentages of the triple bottom lines have 23.08%, 13.46%, and 11.54% for the environmental, economic, and social benefits, respectively. The respondents weighed the importance of obligation to funding source and others at 7.69% and 3.85%, respectively. The other items are (i) that the requirement of the local agency needs to be considered and (ii) that the rating system can be used as a thought framework that integrates sustainability and environmental principles in all design phases.

Third, the respondents were asked whether California DOT needs to develop its own sustainability rating system as a standalone system for infrastructure construction projects in California. As shown in Figure 4, 44% of respondents do not support the necessity of Caltrans' own standalone sustainability rating system, 20% of them neither agree nor disagree, and 36% of the respondents agree that California DOT needs its own sustainability system. These responses trigger further questions regarding which existing sustainability rating tool is the best fit for Californian infrastructure construction projects.

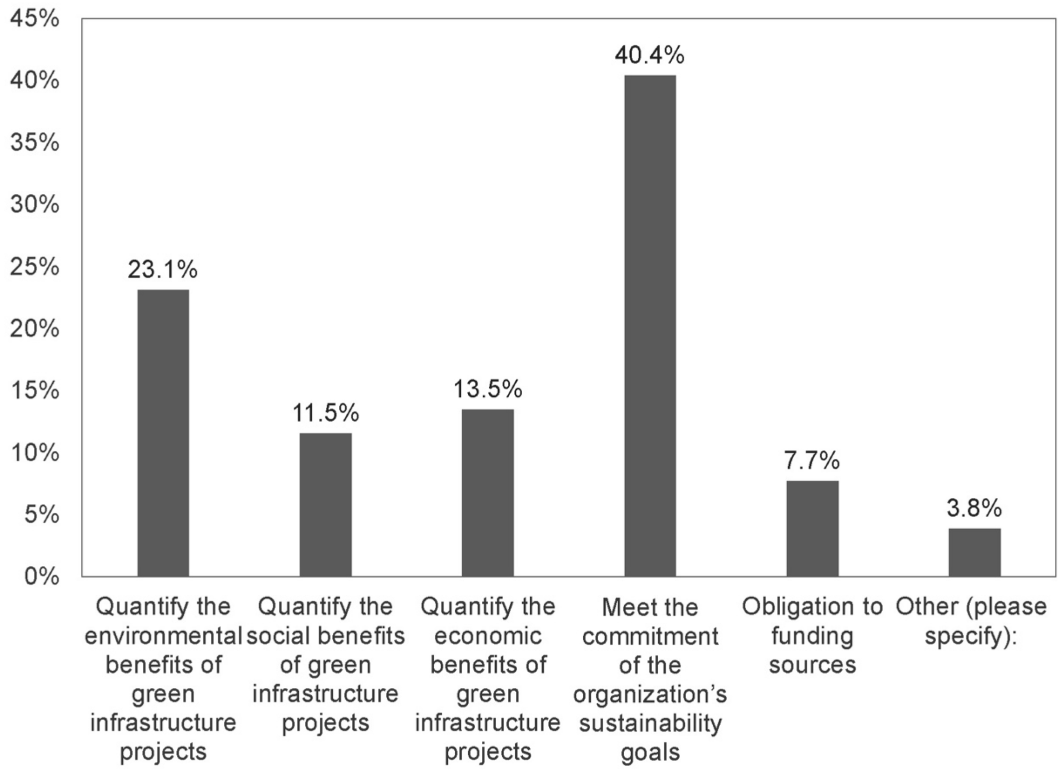

Figure 3. Distribution of Rating Systems' Purposes

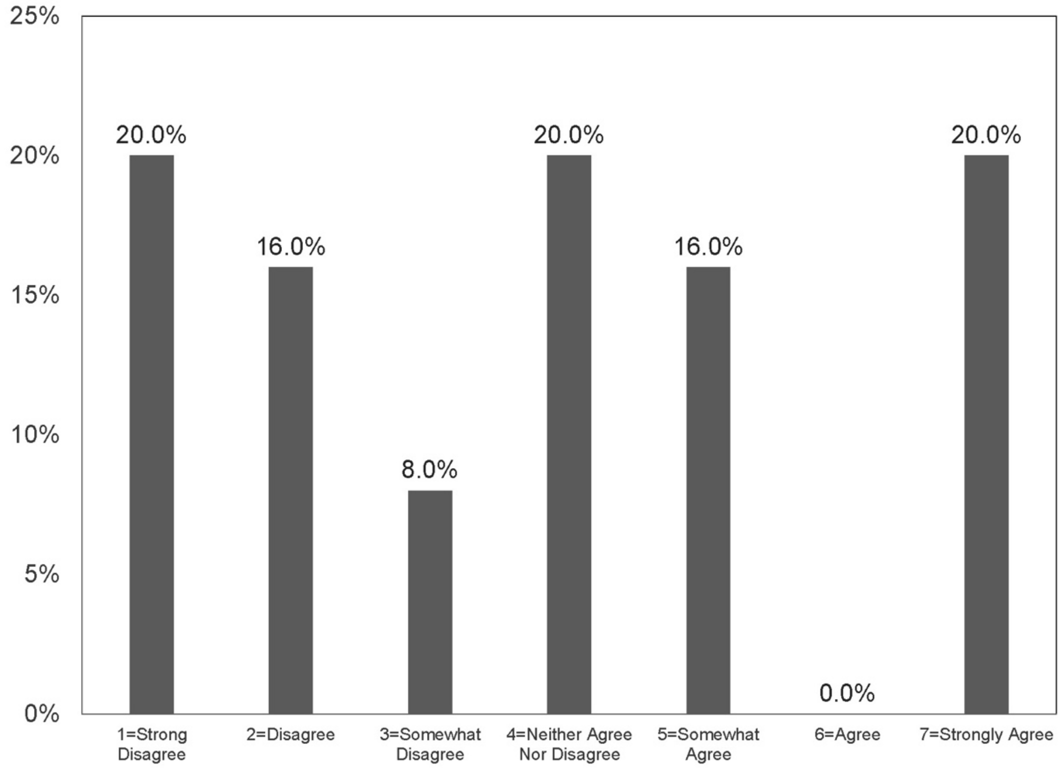

Figure 4. Distribution of the Necessity for a Californian Standalone Rating Systems

Fourth, the respondents were asked to suggest the assessment methods for assessing a sustainability rating system for Californian infrastructure construction projects. Figure 5 shows the distribution of the preferred assessment methods. The responses indicate that the percentages for guidance manual, self-assessment, scoring system, third-party, and others are 28.8%, 25.0%, 23.1%, 17.3%, and 5.80%, respectively. Most respondents think a guidance manual is needed to measure the sustainability of infrastructure construction projects. A guidance manual provides planners, designers, engineers, and stakeholders the ability to incorporate sustainability into all projects. Self-assessment provides for public, private, large, and small projects to achieve higher levels of sustainability for projects. In addition to the guidance manual, self-assessment enables projects of similar size and scope to achieve higher levels of sustainability. A combination of the guidance manual and self-assessment provides the ability for all projects to implement sustainability goals and strive to achieve a higher level of sustainability. The other category includes (i) that funding needs to be tied to sustainability credits, (ii) a national standard can be used, and (iii) a rating system needs to be tied to funding sources.

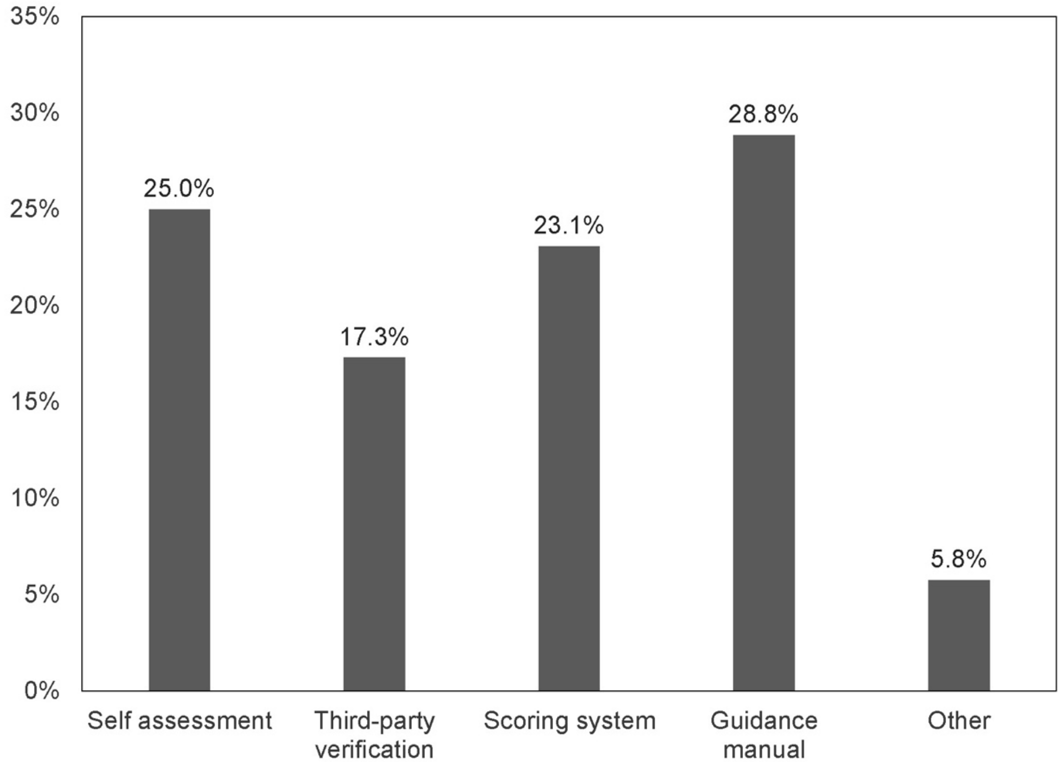

Figure 5. Distribution of Assessment Methods for Sustainability Rating Systems

Fifth, the respondents were asked to indicate the stage of an infrastructure construction project in which the development of a sustainability rating system is most beneficial. As shown in Figure 6, the result indicates that the rating system is most beneficial at the conceptual and design stages (44% and 24%, respectively), while 32% of the respondents did not specify any stage.

Sixth, the measurement methods for development of a sustainability rating system for California infrastructure construction projects were asked to choose from the prescriptive measures, performance measures, comparing to existing projects that were awarded, and others. As shown in Figure 7, the responses showed that prescriptive measures and performance measures earning awarding credits are most beneficial at the percentages of 48.6% and 40.5%, respectively. Prescriptive measures require a project team to satisfy a certain standard to achieve the credits, while performance measures require an entire structure or its elements to perform up to a pre-specified standard. The other opinion was that a comparative approach can be used to allow for unique credits to have a comparison metric. Additionally, all the credits need to have a limit on what can be claimed by considering direct impacts on the project vicinity.

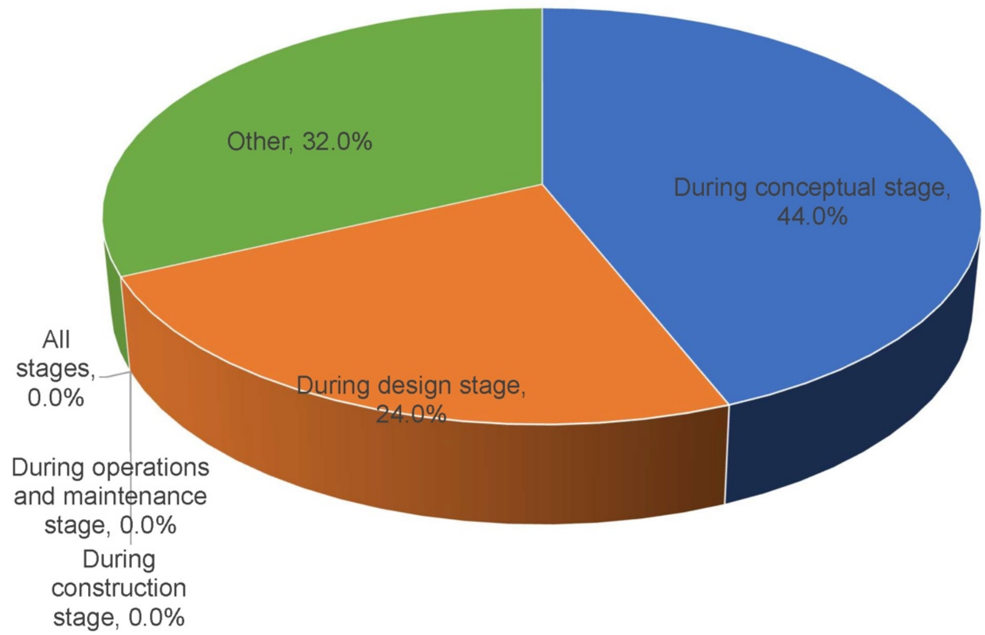

Figure 6. Distribution of the Beneficial Stages for Sustainability Rating Systems

Seventh, the respondents were asked to express whether the California DOT needs to incorporate innovation in design and regional priority into its own sustainability rating systems as does USGBC's LEED system. As shown in Figure 8, 60% of respondents agree, 32% of them neither agree nor disagree, and 8% of them disagree.

Eighth, the respondents were also asked to recommend at least three rating systems that are most beneficial for the development of a sustainability rating system for California infrastructure construction projects from the existing ten rating systems. The responses for the systems asked are 9.4%, 17.9%, 7.5%, 10.4%, 6.6%, 8.5%, 7.5%, 9.4%, 10.4%, and 12.3% for Building Environmentally and Economically Sustainable Transportation Infrastructure-Highways (BE2ST in-Highways), Envision®, Green Guide for Roads, Green Leadership in Transportation Environmental Sustainability (GreenLITES), GreenPave, The Greenroads Rating System (Greenroads), Illinois-Livable and Sustainable Transportation (I-LAST), Infrastructure Voluntary Evaluation Sustainability Tool (INVEST), Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm (CEEQUAL), and Sustainable Transportation Analysis and Rating System (STARS), respectively. Envision® was found to be the most beneficial for development of a sustainability rating system for California infrastructure construction projects from the existing ten rating systems.

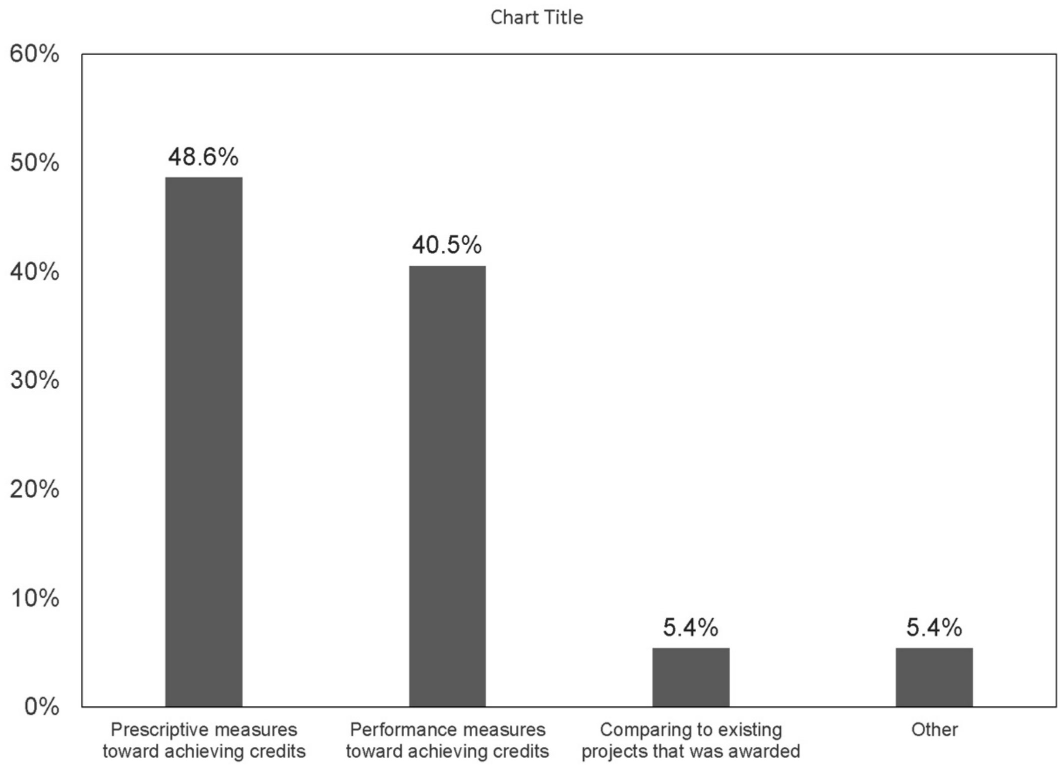

Figure 7. Distribution of Measurement Methods for Sustainability Rating Systems

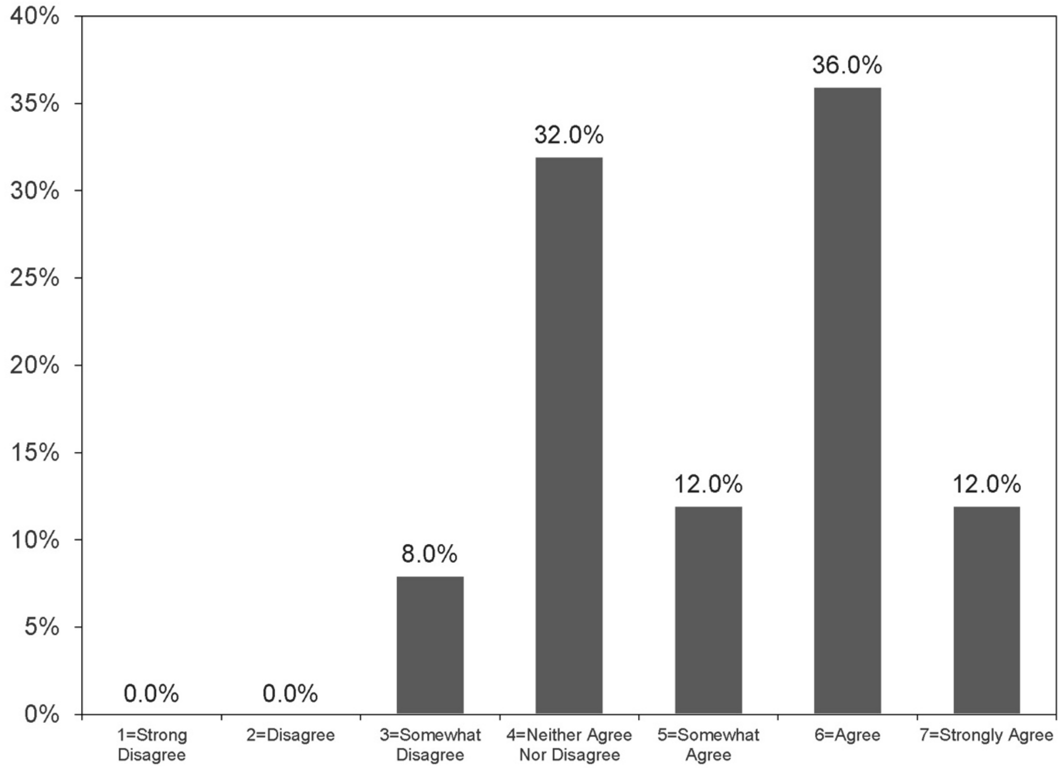

Figure 8. Distribution of the Need for Innovation and Regional Priority

4.2 Importance of Major Categories for Infrastructure Sustainability Systems

Six major categories of infrastructure sustainability systems considered in this survey were compared using the median values for categories if they are statistically equal or not. Kruskal-Wallis tests were used to examine whether the medians for each category differ because data do not follow a normal distribution. The Kruskal-Wallis statistic helps us to test the hypothesis that all population medians are equal among categories. If the null hypothesis of equality of population medians is rejected, then the individual categories are compared using a pair-wise comparison (Minitab 2020).

Table 1 shows the statistical results of the Anderson-Darling tests for normality. For the Anderson-Darling tests, the null and alternative hypotheses are H_0: Data follow a normal distribution and H_1: Data do not follow a normal distribution. Since the p-values for all six major sustainable categories are less than the significance level of 0.05, we reject the null hypothesis that the data follow a normal distribution. The result suggests that non-parametric tests need to be used to analyze the data. Since the one-way ANOVA can tolerate non-normal data with only a small effect on the Type I error rate, it can be also considered a robust test in case the assumption of normality is violated. Table 1 also shows the statistical results on Bartlett's tests of homogeneity of variances. Bartlett's method is used even though this method is only accurate for normal distribution to examine the equal variance among six major sustainable categories. For Bartlett's tests for the equal variance, the null and alternative hypotheses are H_0: All variances are equal and H_1: At least one variance is different. Since the p-values for all six major sustainable categories are greater than the significance level of 0.05, we failed to reject the null hypothesis that all the variances among the data are equal. The result means that equal variance assumptions are met for parametric tests.

Table 1. Results of Normality and Equal Variances

Test	Anderson-Darling			Bartlett's Tests		
Category	Test statistics	P-value	Normality	Test statistics	P-value	Equal variance
Site-Related	6.804	<0.005	No	2.71	0.607	Yes
Water- and Wastewater-Related	10.393	<0.005	No	5.09	0.278	Yes
Energy-Related	11.269	<0.005	No	0.07	0.997	Yes
Materials- and Resources-Related	7.666	<0.005	No	1.08	0.898	Yes
Environmental-Related	8.818	<0.005	No	0.60	0.963	Yes
Other	5.437	<0.005	No	0.55	0.908	Yes

The Likert scale responses usually do not follow the normal distribution as it turned out in Table 1. Thus, we first tested the differences in the median values but not the mean values for the multiple comparisons. Multiple comparison using Kruskal-Wallis tests are conducted to determine whether the medians of two or more groups differ statistically (Minitab 2020). Since equal variance assumption are met for the data, the authors then used ANOVA to test the comparison of the mean values. ANOVA is not very sensitive to moderate deviations from normality and have shown that the false positive rate is not affected by this violation of normality assumption (Glass et al. 1972, Harwell et al. 1992, Lix et al. 1996). This issue can be resolved in the future study by collecting a large number of random samples from a population so that the means of those samples are approximately normally distributed even when the population is not normal.

Table 2 tabulates the statistical results on multiple comparisons for the median values for all six major sustainability categories based on the results obtained from the Kruskal-Wallis tests. For the responses for factors under each category, the hypotheses are H_0: The medians for all six major sustainability categories are equal and H_a: The medians for all six major sustainability categories are not equal. A tie occurs because the same value is in more than one sample due to the nature of Likert scale data. Although the adjusted p-value usually shows more accurate results than the unadjusted p-value, the unadjusted p-value is used because it is always greater than the adjusted p-value and because it is yielded the more conservative estimate. Also note that if no ties exist in the data, the two p-values are equal.

For the responses for all six major categories, we have enough evidence to reject the null hypothesis because the observed significance levels are greater than $\alpha = 0.05$ with test statistics of higher H value. Therefore, we found that there is not sufficient evidence to conclude that at least one median value is different among all six major sustainability categories. The results prompted us to verify that the test has enough power to detect a difference that is practically important. Several ways to increase the power of the hypothesis tests can be made in future research, including (1) collecting more sample data, the most practical way to increase power, (2) using a higher significance level so that the probability of rejecting the null hypothesis is increased, (3) selecting a larger value for the difference, (4) using a one-sided hypothesis, and (5) finding a way to decrease the standard deviation in the process (Minitab 2020).

An analysis of variance (ANOVA) is further conducted to compare the mean response values for six major sustainability categories to determine the difference in the extent to which respondents are weighing the importance levels. The ANOVA tests the null hypothesis that six major sustainability categories are drawn from populations with the same mean values. The authors assumed that respondents' response residuals, which refers to the variability in the variables, are approximately normally distributed, responses are independent, variances of populations are equal, and responses for the six major sustainable categories are independent and identically distributed normal random variables.

The one-way ANOVA was used to test whether there is difference in mean values of respondents' preferences across the six major categories presented in the survey. The null and alternative hypotheses are H_0: $\mu Ci = 0$ for all i, where i is the category, and H_a: at least two mean values among six major sustainable categories differ. At a significance level of 0.05, the null hypotheses are rejected if the p-value is not greater than 0.05, which means there is sufficient evidence to show that the null hypothesis is not true.

Table 2. Results of Multiple Comparison for All Six Major Categories

Test	Test Statistic (H-value)		P-Value		
Category	Not adjusted for ties	Adjusted for ties	Not adjusted for ties	Adjusted for ties	Difference among medians
Site-Related	6.24	6.75	0.182	0.150	No
Water- and Wastewater-Related	4.52	5.18	0.345	0.269	No
Energy-Related	2.29	2.62	0.682	0.623	No
Materials and Resources-Related	2.05	2.24	0.727	0.692	No
Environmental-Related	1.90	2.09	0.755	0.719	No
Others	2.53	2.76	0.471	0.430	No

Table 3 tabulates the ANOVA results for all six major sustainability categories. The one-way ANOVA test yields a p-value of 0.001 less than $\alpha = 0.05$; therefore, we have significant evidence to reject the null hypothesis. The result means that the mean value of one category differs statistically from those of other categories. Tukey's multiple comparison test is used to determine which among the means of the six major categories differ from the rest by comparing the difference between each pair of means with appropriate adjustment for the multiple testing. At a significance level of 0.05, the null hypotheses are rejected because their p-values are less than 0.05. The result means that there is sufficient evidence to claim there is significant difference for the pairwise comparisons between other and water and wastewater-related categories and other and energy-related categories. However, for the rest of the pairwise comparisons, at a significance level of 0.05, the null hypotheses are not rejected because their p-values are greater than 0.05, meaning there is sufficient evidence to claim that the null hypothesis is true. Table 4 shows the results obtained from Tukey simultaneous tests for the differences of means of the six major categories.

Table 3. Results of ANOVA for Multiple Comparison of Six Major Categories

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	28.25	5.650	4.04	0.001
Error	719	1004.86	1.398		
Total	724	1033.11			

Table 4. Results for Differences of Means of Six Major Categories

Difference of Levels	Difference of Means	SE of Difference	95% CI*	T-Value	Adjusted P-Value
Water vs Site	0.272	0.150	(-0.154, 0.698)	1.82	0.453
Energy vs Site	0.240	0.150	(-0.186, 0.666)	1.60	0.595
Materials vs Site	0.024	0.150	(-0.402, 0.450)	0.16	1.000
Environmental vs Site	0.096	0.150	(-0.330, 0.522)	0.64	0.988
Others vs Site	-0.362	0.159	(-0.814, 0.090)	-2.28	0.201
Energy vs Water	-0.032	0.150	(-0.458, 0.394)	-0.21	1.000
Materials vs Water	-0.248	0.150	(-0.674, 0.178)	-1.66	0.560
Environmental vs Water	-0.176	0.150	(-0.602, 0.250)	-1.18	0.848
Others vs Water	-0.634	0.159	(-1.086, -0.182)	-4.00	0.001**
Materials vs Energy	-0.216	0.150	(-0.642, 0.210)	-1.44	0.700
Environmental vs Energy	-0.144	0.150	(-0.570, 0.282)	-0.96	0.930
Others vs Energy	-0.602	0.159	(-1.054, -0.150)	-3.80	0.002 **
Environmental vs Materials	0.072	0.150	(-0.354, 0.498)	0.48	0.997
Others vs Materials	-0.386	0.159	(-0.838, 0.066)	-2.43	0.145
Others vs Environmental	-0.458	0.159	(-0.910, -0.006)	-2.89	0.045 **

* Individual confidence level = 99.55%; ** Statistically significant

We conducted the ANOVA test excluding the other category to further compare the mean response rates of five major sustainable categories to determine the difference in the extent to which respondents weigh the importance levels. The null and alternative hypotheses are H_0: $\mu Ci = 0$ for all i, where i is the category, and H_a: at least two mean values among five major sustainable categories differ. Table 5 tabulates the ANOVA results without the other category. The one-way ANOVA test yields a p-value of 0.244 greater than $\alpha = 0.05$; therefore, we do not have a significant evidence to reject the null hypothesis. The result indicates that the mean value of one category does not differ statistically from those of other categories. The result of the test indicates that the respondents valued all five categories equally and did not undervalue any one of the categories considered in the survey. Tukey's multiple comparison test is used to determine which means among the means of five major sustainable categories differ from the rest by assessing the difference between each pair of means with appropriate adjustment for the multiple testing. The null hypotheses for all the pairwise comparisons are not rejected because their p-values are greater than 0.05, meaning there is sufficient evidence to show that the null hypothesis is true (Minitab 2020). Table 6 shows the results obtained from Tukey simultaneous tests for the differences of means of five major sustainable categories.

Table 5. Results of ANOVA for Multiple Comparison of Five Major Categories

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	7.686	1.922	1.37	0.244
Error	620	871.072	1.405		
Total	624	878.758			

Table 6. Results for Differences of Means of Five Major Categories

Difference of Levels	Difference of Means	SE of Difference	95% CI*	T-Value	Adjusted P-Value
Water vs Site	0.272	0.150	(-0.137, 0.681)	1.81	0.365
Energy vs Site	0.240	0.150	(-0.169, 0.649)	1.60	0.497
Materials vs Site	0.024	0.150	(-0.385, 0.433)	0.16	1.000
Environmental vs Site	0.096	0.150	(-0.313, 0.505)	0.64	0.968
Energy vs Water	-0.032	0.150	(-0.441, 0.377)	-0.21	1.000
Materials vs Water	-0.248	0.150	(-0.657, 0.161)	-1.65	0.463
Environmental vs Water	-0.176	0.150	(-0.585, 0.233)	-1.17	0.766
Materials vs Energy	-0.216	0.150	(-0.625, 0.193)	-1.44	0.601
Environmental vs Energy	-0.144	0.150	(-0.553, 0.265)	-0.96	0.873
Environmental vs Materials	0.072	0.150	(-0.337, 0.481)	0.48	0.989

* Individual confidence level = 99.35%

4.3 Importance of Factors for Infrastructure Sustainability Systems

The authors used the Kruskal-Wallis test to examine the importance levels of related factors under each category to see whether respondents prefer a specific factor. The Kruskal-Wallis test outcomes provide the mean rank that is calculated as the average of the ranks for all responses within each factor along with its corresponding z-value. Higher mean ranks are interpreted as the observation values in the group is higher than those of the other groups. The corresponding z-values indicate how the average rank for each group compares to the average rank of all the observations. A negative z-value indicates that a factor's average rank is less than the overall average rank, while a positive z-value means that a factor's average rank is greater than the overall average rank. The higher the absolute value, the further a factor's average rank is from the overall average rank (Minitab 2020).

Analysis of Site-Related Categories

Site-related categories include (1) locate sustainable sites, (2) plan and design effectively and efficiently, (3) enhance mobility and sustainable transportation, (4) reduce environmental impacts on ecology, biodiversity, historic areas, and (5) minimize noise, vibration, and light pollution. Table 7 tabulates the descriptive statistical results. For the responses in the scales of "strongly agree" and "agree" on the importance levels of each factor, the respondents indicated 60%, 64%, 80%, 60%, and 56% for the factors (1), (2), (3), (4), and (5), respectively. The authors further examined the importance levels of five factors to see whether respondents have a preference for a specific factor. In doing so, we used the z-value; a positive z-value means that the mean rank is higher than the overall mean rank. The z-values of five factors under site-related category are -1.14, -0.39, 2.42, -0.21, and -0.68 for factors (1), (2), (3), (4), and (5), respectively. The result shows that the respondents expressed the greatest weight on the factor of "(3) enhance mobility and sustainable transportation," having a mean rank of 78.7 and z-value of 2.42, which means its mean rank is higher than the overall mean rank.

Table 7. Results of Responses for Site-Related Categories

Response	(1) Locate sustainable sites n(%)	(2) Plan and design effectively and efficiently n(%)	(3) Enhance mobility and sustainable transportation n(%)	(4) Reduce environmental impacts on ecology, biodiversity, historic areas n(%)	(5) Minimize noise, vibration, and light pollution n(%)
7=Strongly Disagree	0(0)	0(0)	0(0)	0(0)	0(0)
6=Disagree	1(4)	0(0)	0(0)	0(0)	0(0)
5=Somewhat Disagree	0(0)	0(0)	0(0)	2(8)	1(4)
4=Neither Agree Nor Disagree	6(24)	7(28)	2(8)	3(12)	3(12)
3=Somewhat Agree	3(12)	2(8)	3(12)	5(20)	7(28)
2=Agree	9(36)	8(32)	6(24)	6(24)	7(28)
1=Strong Agree	6(24)	8(32)	14(56)	9(36)	7(28)
Total	25(100)	25(100)	25(100)	25(100)	25(100)
Statistics: Mode	6	6	7	7	5
Median	6	6	7	6	6
Mean	5.48	5.68	6.28	5.68	5.64
Std. Dev.	1.33	1.22	0.98	1.31	1.15
Mean Rank	55.6	60.5	**78.7**	61.6	58.6
Z-value	-1.14	-0.39	**2.42**	-0.21	-0.68

Analysis of Water- and Wastewater-Related Categories

Water-related categories include (1) reduce water consumption, (2) treat and manage stormwater, (3) reduce and treat stormwater runoff, (4) protect water quality, and (5) reduce impervious areas. Table 8 tabulates the descriptive statistical results. The authors further examined the importance levels of five factors under the water- and wastewater-related category to identify whether respondents prefer a specific factor. The z-values of the five factors are 0.32, 1.01, -1.06, 1.17, and -1.44 for factors (1), (2), (3), (4), and (5), respectively. The result shows that the respondents placed greater weight on the factors “(4) protect water quality,” “(2) treat and manage stormwater,” and "(1) reduce water consumption," having mean ranks of 70.6, 69.5, and 65.1 with their z-values of 1.17, 1.01, and 0.32, respectively. These positive z-values indicate that their mean ranks are higher than the overall mean rank.

Table 8. Results of Responses for Water and Wastewater-Related Categories

Response	(1) Reduce water consumption n(%)	(2) Treat and manage stormwater n(%)	(3) Reduce and treat stormwater runoff n(%)	(4) Protect water quality n(%)	(5) Reduce impervious areas n(%)
7=Strongly Disagree	0(0)	0(0)	0(0)	0(0)	0(0)
6=Disagree	0(0)	0(0)	1(4)	0(0)	1(4)
5=Somewhat Disagree	0(0)	0(0)	1(4)	1(4)	1(4)
4=Neither Agree Nor Disagree	2(8)	3(12)	3(12)	3(12)	2(8)
3=Somewhat Agree	4(16)	0(0)	2(8)	1(4)	4(16)
2=Agree	7(28)	9(36)	9(36)	5(20)	9(36)
1=Strong Agree	12(48)	13(52)	9(36)	15(60)	8(32)
Total	25(100)	25(100)	25(100)	25(100)	25(100)
Statistics: Mode	7	7	7	7	6
Median	6	7	6	7	6
Mean	6.16	6.28	5.76	6.20	5.72
Std. Dev.	0.99	0.98	1.39	1.22	1.34
Mean Rank	**65.1**	**69.5**	56.1	**70.6**	53.7
Z-value	**0.32**	**1.01**	-1.06	**1.17**	-1.44

Analysis of Energy-Related Factors

Energy-related categories include (1) reduce energy consumption, (2) reduce greenhouse gas emissions, (3) reduce pollution, (4) consume renewable energy, and (5) reduce or eliminate volatile organic compounds. Table 9 tabulates the descriptive statistical results. For the responses in the scales of strongly agree and agree on the importance levels of each factor, the respondents indicated 72%, 80%, 80%, 76%, and 80% for the factors (1), (2), (3), (4), and (5), respectively. The authors further examined the importance levels of five factors under the energy-related category to see if respondents have the preference to a specific factor. The z-values of five factors under the energy-related category are -0.48, 1.32, 0.35, -0.40, and -0.79 for factors (1), (2), (3), (4), and (5), respectively. The result shows that the respondents placed greater weight on the factors "(2) reduce greenhouse gas emissions" and "(3) reduce pollutions," having mean ranks of 71.5 and 65.2 with z-values of 1.32 and 0.35, respectively. These positive z-values indicate that their mean ranks are higher than the overall mean rank.

Table 9. Results of Responses for Energy-Related Categories

	(1) Reduce energy consumption	(2) Reduce greenhouse gas emissions	(3) Reduce pollutions	(4) Consume renewable energy	(5) Reduce or eliminate volatile organic compounds
Response	n(%)	n(%)	n(%)	n(%)	n(%)
7=Strongly Disagree	0(0)	0(0)	0(0)	0(0)	0(0)
6=Disagree	0(0)	0(0)	0(0)	0(0)	1(4)
5=Somewhat Disagree	0(0)	1(4)	1(4)	1(4)	0(0)
4=Neither Agree Nor Disagree	5(20)	3(12)	4(16)	4(16)	3(12)
3=Somewhat Agree	2(8)	1(4)	0(0)	1(4)	1(4)
2=Agree	8(32)	5(20)	8(32)	9(36)	12(48)
1=Strong Agree	10(40)	15(60)	12(48)	10(40)	8(32)
Total	25(100)	25(100)	25(100)	25(100)	25(100)
Statistics: Mode	7	7	7	7	6
Median	6	7	7	6	6
Mean	5.92	**6.20**	**6.20**	5.92	5.88
Std. Dev.	1.15	1.22	1.22	1.22	1.24
Mean Rank	59.9	**71.5**	**65.2**	60.4	57.9
Z-value	-0.48	**1.32**	**0.35**	-0.40	-0.79

Analysis of Materials- and Resources-Related Categories

Materials and resources-related categories include (1) utilize the materials and resources effectively and efficiently, (2) reduce waste including in situ and ex situ materials, (3) eliminate hazardous waste, (4) improve construction quality, and (5) utilize the life cycle cost and life cost analysis. Table 10 tabulates the descriptive statistical results. For the responses in the scales of strongly agree and agree on the importance levels of each factor, the respondents indicated 72%, 68%, 76%, 68%, and 56% for the factors (1), (2), (3), (4), and (5), respectively. The authors further examined the importance levels of five factors under the materials and resources-related category to see if respondents have the preference to a specific factor. The z-values of the factors under the energy-related category are 0.78, -0.37, 0.84, -0.23, and -1.02 for the factors (1), (2), (3), (4), and (5), respectively. Respondents placed greater weight on the factors "(3) eliminate hazardous waste" and "(1) utilize the materials and resources effectively and efficiently," having mean ranks of 68.5 and 68.1 with z-values of 0.84 and 0.78, respectively. These positive z-values means their mean ranks are higher than the overall mean rank.

Table 10. Results of Responses for Materials- and Resources-Related Categories

	(1) Utilize the materials and resources effectively and efficiently	(2) Reduce waste including in situ and ex situ materials	(3) Eliminate hazardous waste	(4) Improve construction quality	(5) Utilize the life cycle cost and life cost analysis
Response	n(%)	n(%)	n(%)	n(%)	n(%)
7=Strongly Disagree	0(0)	0(0)	0(0)	0(0)	0(0)
6=Disagree	0(0)	0(0)	0(0)	0(0)	1(4)
5=Somewhat Disagree	0(0)	1(4)	0(0)	1(4)	0(0)
4=Neither Agree Nor Disagree	4(16)	4(16)	5(20)	5(20)	5(20)
3=Somewhat Agree	3(12)	3(12)	1(4)	2(8)	5(20)
2=Agree	8(32)	10(40)	9(36)	9(36)	7(28)
1=Strong Agree	10(40)	7(28)	10(40)	8(32)	7(28)
Total	25(100)	25(100)	25(100)	25(100)	25(100)
Statistics: Mode	7	6	7	6	7
Median	6	6	6	6	6
Mean	5.96	5.72	5.96	5.72	5.52
Std. Dev.	1.10	1.17	1.14	1.24	1.33
Mean Rank	**68.1**	60.6	**68.5**	61.5	56.4
Z-value	**0.78**	-0.37	**0.84**	-0.23	-1.02

Analysis of Environmental-Related Categories

Environmental-related categories include (1) improve the quality of life for Californians and local community, (2) improve economic opportunities to local communities and households, (3) protect, enhance, or restore wildlife, (4) improve air quality using traffic flow, and (5) improve bicycle and pedestrian facilities. Table 11 tabulates the descriptive statistical results. For the responses in the scales of strongly agree and agree on the importance levels of each factor, the respondents indicated 84%, 60%, 64%, 68%, and 72% for the factors (1), (2), (3), (4), and (5), respectively. The authors further examined the importance levels of five factors under the materials and resources-related category to see if respondents have the preference to a specific factor. The z-values are 0.79, -1.28, 0.08, 0.25, and 0.16 for the factors (1), (2), (3), (4), and (5), respectively. The result shows that the respondents placed greater weight on the factors "(1) improve the quality of life for Californians and local community," "(4) improve air quality using traffic flow," "(5) improve bicycle and pedestrian facilities," and "(3) protect, enhance, or restore wildlife," having mean ranks of 68.1, 64.6, 64.0, and 63.5 with z-values of 0.79, 0.25, 0.16, and 0.08, respectively. These positive z-values mean their mean ranks are higher than the overall mean rank.

Table 11. Results of Responses for Environmental-Related Categories

	(1) Improve the quality of life for Californians and local community	(2) Improve economic opportunities to local communities and households	(3) Protect, enhance, or restore wildlife	(4) Improve air quality using traffic flow	(5) Improve bicycle and pedestrian facilities
Response	n(%)	n(%)	n(%)	n(%)	n(%)
7=Strongly Disagree	0(0)	0(0)	0(0)	0(0)	0(0)
6=Disagree	0(0)	0(0)	0(0)	0(0)	0(0)
5=Somewhat Disagree	0(0)	0(0)	0(0)	0(0)	0(0)
4=Neither Agree Nor Disagree	4(16)	6(24)	5(20)	5(20)	5(20)
3=Somewhat Agree	0(0)	4(16)	4(16)	3(12)	2(8)
2=Agree	12(48)	9(36)	6(24)	7(28)	9(36)
1=Strong Agree	9(36)	6(24)	10(40)	10(40)	9(36)
Total	25(100)	25(100)	25(100)	25(100)	25(100)
Statistics: Mode	6	6	7	7	7
Median	6	6	6	6	6
Mean	6.04	5.60	5.84	5.88	5.88
Std. Dev.	1.02	1.12	1.18	1.17	1.13
Mean Rank	**68.1**	54.7	**63.5**	**64.6**	**64.0**
Z-value	**0.79**	-1.28	**0.08**	**0.25**	**0.16**

Analysis of Other Factors

Other categories include (1) advance technologies for transportation projects, (2) incorporate project management practices, including operation and maintenance, (3) encourage innovation in design, and (4) consider regional priority. Table 12 tabulates the descriptive statistical results. For the responses in the scales of strongly agree and agree on the importance levels of each factor, the respondents indicated 56%, 48%, 64%, and 56% for the factors of (1) advance technologies for transportation projects, (2) incorporate project management practices, including operation and maintenance, (3) encourage innovation in design, and (4) consider regional priority, respectively. The authors further examined the importance levels of five factors under others category to see if respondents have the preference to a specific factor. The z-values are -0.02, -1.18, 1.39, and -0.20 for factors (1), (2), (3), and (4), respectively. The result shows that the respondents placed greater weight on the factors "(3) encourage innovation in design," having the mean rank of 57.5 with z-value 1.39. The positive z-value means the mean rank is higher than the overall mean rank.

Table 12. Results of Responses for Other Categories

	(1) Advance technologies for transportation projects	(2) Incorporate project management practices, including operation and maintenance	(3) Encourage innovation in design	(4) Consider regional priority
Response	n(%)	n(%)	n(%)	n(%)
7=Strongly Disagree	0(0)	0(0)	0(0)	0(0)
6=Disagree	0(0)	0(0)	0(0)	0(0)
5=Somewhat Disagree	0(0)	3(12)	0(0)	1(4)
4=Neither Agree Nor Disagree	8(32)	6(24)	6(24)	6(24)
3=Somewhat Agree	3(12)	4(16)	3(12)	4(16)
2=Agree	10(40)	9(36)	9(36)	11(44)
1=Strong Agree	4(16)	3(12)	7(28)	3(12)
Total	25(100)	25(100)	25(100)	25(100)
Statistics: Mode	6	6	6	6
Median	6	5	6	6
Mean	5.40	5.12	5.68	5.36
Std. Dev.	1.12	1.27	1.14	1.11
Mean Rank	50.4	44.6	**57.5**	49.5
Z-value	-0.02	-1.18	**1.39**	-0.20

Table 13 summarizes the mean ranks based on the positive z-values among the factors under each of the six major sustainability categories. As previously mentioned, the factor(s) with the positive z-values have average rank greater than the overall average rank among the factors considered. For the site-related categories, the respondents ranked the enhancement of mobility and sustainable transportation as the first among five factors. For the water- and wastewater-related categories, protection of water quality, treatment and management of stormwater, and reduction of water consumption are the factors that the respondents gave more importance than other factors. For the energy-related category, the respondents ranked the reduction of greenhouse gas emissions highest, followed by the reduction of pollution. For materials- and resources-related categories, the elimination of hazardous waste is the most important factor, followed by the utilization of the materials and resources effectively and efficiently. For the environmental-related categories, the respondents ranked the improvement of the quality of life for Californian and local community highest, followed by the improvement of air quality using traffic flow, the improvement of bicycle and pedestrian facilities, and the protection, enhancement, and restoration of wildlife. The results show that a few factors under each of the six major sustainability categories have received higher ranks than other factors.

Table 13. Results of Mean Ranks among Factors within Each Category

Category	Factor	Z-Value	Rank
Site-related category	(1) Locate sustainable sites	-1.14	5
	(2) Plan and design effectively and efficiently	-0.39	3
	(3) Enhance mobility and sustainable transportation	2.42	1
	(4) Reduce environmental impacts on ecology, biodiversity, historic areas	-0.21	2
	(5) Minimize noise, vibration, and light pollution	-0.68	4
Water and wastewater-related category	(1) Reduce water consumption	0.32	3
	(2) Treat and manage stormwater	1.01	2
	(3) Reduce and treat stormwater runoff	-1.06	4
	(4) Protect water quality	1.17	1
	(5) Reduce impervious areas	-1.44	5
Energy-related category	(1) Reduce energy consumption	-0.48	4
	(2) Reduce greenhouse gas emissions	1.32	1
	(3) Reduce pollutions	0.35	2
	(4) Consume renewable energy	-0.40	3
	(5) Reduce or eliminate volatile organic compounds	-0.79	5
Materials and resources-related category	(1) Utilize the materials and resources effectively and efficiently	0.78	2
	(2) Reduce waste including in situ and ex situ materials	-0.37	4
	(3) Eliminate hazardous waste	0.84	1
	(4) Improve construction quality	-0.23	3
	(5) Utilize the life cycle cost and life cost analysis	-1.02	5
Environmental-related category	(1) Improve the quality of life for Californians and local community	0.79	1
	(2) Improve economic opportunities to local communities and households	-1.28	5
	(3) Protect, enhance, or restore wildlife	0.08	4
	(4) Improve air quality using traffic flow	0.25	2
	(5) Improve bicycle and pedestrian facilities	0.16	3
Others category	(1) Advance technologies for transportation projects	-0.02	2
	(2) Incorporate project management practices, including operation and maintenance	-1.18	4

Category	Factor	Z-Value	Rank
	(3) Encourage innovation in design	1.39	1
	(4) Consider regional priority	-0.20	3

4.4 Open-Ended Responses: Expectations and Opinions About the Improvement of Infrastructure Sustainability Systems

To understand respondents' expectations and ideas about improving the infrastructure sustainability systems, we asked open-ended questions. First, the respondents expressed their opinions on the design and/or performance measures to incorporate into a sustainability rating system for California infrastructure construction projects. Refer to Appendix B for the full list of responses. The respondents expressed the need to develop a measurable performance metric not only for the major sustainability determinants but also project management functions. They also indicated the need to consider the true value of a project life cycle cost and the way to support local priorities when evaluating sustainability goals of infrastructure construction projects.

Second, the respondents expressed their opinions on how to improve sustainability for California infrastructure construction projects. Refer to Appendix B for the full list of responses. The respondents expressed the interest in adopting the existing rating systems rather than developing a new rating system for California infrastructure construction projects unless the new system equally assess the sustainability goals and result in consistent quality and resiliency. Since the planning, environmental, design and construction experts are not well integrated, there is a need to implement a better cross expertise education so that they can raise the multiple skills that are required to evaluate sustainability goals. Also, it is notable that any rating system cannot fit to evaluate the sustainability goals for all the infrastructure construction projects.

5. Summary & Conclusions

The authors presented the statistical results on the important factors that affect success in meeting sustainability goals of infrastructure construction projects based on the survey administered to infrastructure industry professionals in California. The results indicated that the median response values for the six major sustainability categories do not show any significant difference. The results also showed that no statistically significant difference in the mean response values can be found from the six major sustainability categories considered. Based on the pairwise comparison results, only the other category showed difference with water- and energy-related categories. These findings mean that these categories are equally important determinants, for the respondents, of the successful implementation of sustainability in infrastructure construction projects in California.

The results of quantitative analysis presented in this report will help assess the awareness of infrastructure industry professionals for key high-performance sustainability requirements that are being built into the designs of infrastructure construction projects in California. The outcomes will not only provide information about specific sustainability categories and related factors for the development of a rating system for California's infrastructure sustainability efforts, but it will also enhance the sustainability strategies for future infrastructure construction projects. Furthermore, the project team may pursue the various certifications. These findings will be helpful in developing a framework for a Californian infrastructure sustainability rating system because the results encompass the geographical, social, economic, and environmental aspects of Californian infrastructure construction projects.

While this report presented an empirical contribution for development of a framework of California infrastructure sustainability rating system, several limitations remain. address these limitations for the research community include:

- Need to expand this survey to general construction personnel or subcontractors to incorporate their voices and compare them with the results obtained from this survey for infrastructure sustainability systems,

- Collecting more sample data, which is the most practical way to increase power of a hypothesis test; a higher significance level needs to be considered to increase the research hypothesis statement by rejecting the null hypothesis.

- Comparing the results with other states' sustainability rating systems for infrastructure construction projects.

Appendix A Survey Form

Approved October 18, 2021 by the CSULB IRB

Project Title: Development of Framework for California Infrastructure Sustainability Rating System

Project investigator: Dr. Joseph Kim (joseph.kim@csulb.edu)
Student assistant: Patricia McCarthy (patricia.mccarthy01@student.csulb.edu)

Department of Civil Engineering and Construction Engineering Management
California State University Long Beach
1250 Bellflower Blvd., Long Beach, CA 90840

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Approved October 18, 2021 by the CSULB IRB

CONSENT TO PARTICIPATE IN RESEARCH

[Development of Framework for California Infrastructure Sustainability Rating System]

You are kindly asked to participate in a research study conducted by Dr. Joseph Kim, Principal Investigator, from the Department of Civil Engineering and Construction Engineering Management at California State University, Long Beach. You were selected as a possible participant in this study because you are an engineer, designer, contractor, construction manager, government agency who are involved in California infrastructure projects.

PURPOSE OF THE STUDY

This survey aims to assess the awareness of key high-performance sustainability requirements of California infrastructure projects and to use the key determinants for developing a framework of a California infrastructure sustainability rating system. The research outcome is to produce a high-quality survey data and analysis results on key high-performance sustainability requirements of California infrastructure projects, which will be of great interest to the transportation agencies for their selection of the right rating systems to measure their sustainability efforts.

PROCEDURES

If you volunteer to participate in this study, then you will complete the survey forms distributed to you online. The survey will take ten minutes to complete. This survey project will be completed within twelve months upon the approval of University IRB.

POTENTIAL RISKS AND DISCOMFORTS

Risk #1: Loss of confidentiality. Mitigation for Risk #1: No personal information is collected, except for their industry experience. Data will be stored on secure, password-protected computers at California State University Long Beach, and only PI and student assistant who work on the project will have access. Risk #2: Coercion. Mitigation for Risk #2: The survey is voluntary, and the project team will not force you to answer the survey. You can decline the survey request at any time due to your busy schedule or any other matters. Risk #3: Discomfort answering questions. Mitigation for Risk #3: You can exit the survey completely at any moment if you are not comfortable to answer questions. However, incomplete surveys will be eliminated when conducting data analysis. No other risks are expected for your participation in the survey.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

No direct benefits. Upon request via email, project teams will provide you with data analysis.

PAYMENT FOR PARTICIPATION

No payment is involved.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Data analysis conducted through this survey will be presented to CSU Chancellor's office as a final report and to the journal and/or conference publications as a research paper format. No identifying information will be used in the report.

IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the survey, please feel free to contact Dr. Joseph Kim at joseph.kim@csulb.edu or at 562-985-1679.

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights, or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact the Office of University Research, CSU Long Beach, 1250 Bellflower Blvd., Long Beach, CA 90840; Telephone: (562) 985-5314 or email to irb@csulb.edu.

I voluntarily consent to participate in this survey.

Yes No

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0% 100%

Q1. Approximately **how many years** have you worked for infrastructure construction projects? **Please enter a number 0-60**. If you are not sure, please estimate.

Q2. What is your current role or job? Please select all that apply.

- Engineer
- Designer
- Contractor
- Construction manager
- Inspector
- Government Agency (Please specify your role)
- Other (please specify)

Q3. How many projects have you used any sustainability rating system? Please write a number from 0~100. If you are not sure, please estimate.

← →

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Q4. Which of the sustainability rating systems has your organization or company used or been using in your projects? Please select all that apply.

- Infrastructure Voluntary Evaluation Sustainability Tool (INVEST)
- Green Leadership in Transportation Environmental Sustainability (GreenLITES)
- Illinois-Livable and Sustainable Transportation (I-LAST)
- The Greenroads Rating System (Greenroads)
- Envision®
- Building Environmentally and Economically Sustainable Transportation Infrastructure-Highways (BE2ST in-Highways)
- GreenPave
- Green Guide for Roads
- Sustainable Transportation Analysis and Rating System (STARS)
- Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm (CEEQUAL)
- Other (please specify):

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Q5. What purposes have you used any sustainability rating system? Please select all that apply.

- Quantify the environmental benefits of green infrastructure projects
- Quantify the social benefits of green infrastructure projects
- Quantify the economic benefits of green infrastructure projects
- Meet the commitment of the organization's sustainability goals
- Obligation to funding sources
- Other (please specify):

← →

Q6. Do you agree that California DOT needs to develop its own sustainability rating system as a stand-alone system for California infrastructure projects like other DOTs?

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Disagree
- Strongly agree

Q7. Which of the following components is most beneficial for development of a sustainability rating system for California infrastructure construction projects.? Please select all that apply.

- Self-assessment
- Third-party verification
- Scoring system
- Guidance Manual
- Other (please specify)

←   →

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Q8. Which of the following stages is most beneficial for development of a sustainability rating system for California infrastructure construction projects.? Please select one answer.

- During conceptual stage
- During design stage
- During construction stage
- During operations and maintenance stage
- All stages
- Other (please specify)

Q9. Which of the following measurement strategies is most beneficial for development of a sustainability rating system for California infrastructure construction projects.? Please select all that apply.

- Prescriptive measures toward achieving credits
- Performance measures toward achieving credits
- Comparing to existing projects that was awarded
- Other (please specify):

Q10. Do you agree that **innovation in design and regional priority** are needed for development of a sustainability rating system for California infrastructure construction projects like USGBC's LEED system?

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

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Q11. Please **Select at least THREE rating systems** that you think the most beneficial system for development of a sustainability rating system for California infrastructure construction projects.

- Building Environmentally and Economically Sustainable Transportation Infrastructure-Highways (BE2ST in-Highways)
- Envision®
- Green Guide for Roads
- Green Leadership in Transportation Environmental Sustainability (GreenLITES)
- GreenPave
- The Greenroads Rating System (Greenroads)
- Illinois-Livable and Sustainable Transportation (I-LAST)
- Infrastructure Voluntary Evaluation Sustainability Tool (INVEST)
- Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm (CEEQUAL)
- Sustainable Transportation Analysis and Rating System (STARS)

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Q12. Please indicate the extent which you “Agree” or “Disagree” with the **Site-related factors** for development of a sustainability rating system for California infrastructure construction projects.

Site-related factors

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Locate sustainable sites	○	○	○	○	○	○	○
Plan and design effectively and efficiently	○	○	○	○	○	○	○
Enhance mobility and sustainable transportation	○	○	○	○	○	○	○
Reduce environmental impacts on ecology, biodiversity, historic areas	○	○	○	○	○	○	○
Minimize noise, vibration, and light pollution	○	○	○	○	○	○	○

Q13. Please indicate the extent which you “Agree” or “Disagree” with the **Water and Wastewater-related factors** for development of a sustainability rating system for California infrastructure construction projects.

Water and Wastewater-related factors

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reduce water consumption	○	○	○	○	○	○	○
Treat and manage stormwater	○	○	○	○	○	○	○
Reduce and treat stormwater runoff	○	○	○	○	○	○	○
Protect water quality	○	○	○	○	○	○	○
Reduce impervious areas	○	○	○	○	○	○	○

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Q14. Please indicate the extent which you “Agree” or “Disagree” with the **Energy related factors** for development of a sustainability rating system for California infrastructure construction projects.

Energy related factors

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reduce energy consumption	○	○	○	○	○	○	○
Reduce greenhouse gas emissions	○	○	○	○	○	○	○
Reduce pollutions	○	○	○	○	○	○	○
Consume renewable energy	○	○	○	○	○	○	○
Reduce or eliminate volatile organic compounds	○	○	○	○	○	○	○

Q15. Please indicate the extent which you “Agree” or “Disagree” with the **Materials related factors** for development of a sustainability rating system for California infrastructure construction projects.

Material related factors

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Utilize the materials and resources effectively and efficiently	○	○	○	○	○	○	○
Reduce waste including in situ and ex situ materials	○	○	○	○	○	○	○
Eliminate hazardous waste	○	○	○	○	○	○	○
Improve construction quality	○	○	○	○	○	○	○
Utilize the life cycle cost and life cost analysis	○	○	○	○	○	○	○

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Q16. Please indicate the extent which you “Agree” or “Disagree” with the **Environmental related factors** for development of a sustainability rating system for California infrastructure construction projects.

Environmental related factors

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Improve the quality of life for Californians and local community	○	○	○	○	○	○	○
Improve economic opportunities to local communities and households	○	○	○	○	○	○	○
Protect, enhance, or restore wildlife	○	○	○	○	○	○	○
Improve air quality using traffic flow	○	○	○	○	○	○	○
Improve bicycle and pedestrian facilities	○	○	○	○	○	○	○

Q17. Please indicate the extent which you “Agree” or “Disagree” with the **Other factors** for development of a sustainability rating system for California infrastructure construction projects.

Other factors

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Advance technologies for transportation projects	○	○	○	○	○	○	○
Incorporate project management practices, including operation and maintenance	○	○	○	○	○	○	○
Encourage innovation in design	○	○	○	○	○	○	○
Consider regional priority	○	○	○	○	○	○	○

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Q18. What **design and/or performance measures** are necessary to incorporate when developing a sustainability rating system for California infrastructure construction projects? Feel free to write.

Q19. Please feel free to write your opinion on **how to improve the sustainability for the California infrastructure construction projects**, and about what they have to do.

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0% 100%

We thank you for your time spent taking this survey.
Your response has been recorded.

0% 100%

Appendix B for Open-Ended Responses

First, the respondents expressed their opinions on the design and/or performance measures to incorporate into a sustainability rating system for California infrastructure construction projects, as follows:

- Incorporating measurable reductions in energy, water and material use, and pollution
- Incorporating performance measures for effective project team collaboration, community involvement and design for resiliency
- Evaluating a metric to assess up front capital cost increase versus long term operation and maintenance (O&M) savings because many sustainable options are eliminated early given larger upfront costs when compared to more traditional non-sustainable options.
- A standardized calculator for these types of evaluations would help maintain sustainable options further into the project life cycle to help decision makers understand the longer-term benefits of sustainable infrastructure implementation; resiliency to climate change and equitable infrastructure design, be consistent, a rating factor that is easy to follow, should not come at a high price
- Consider life cycle for some measurable ways to determine what the appropriate life cycle of a project is
- A way to adapt to rapid changes in technology, materials, methods, etc.
- How do we know what a correct life cycle is when analyzing a project?
- Goals for every stage of the project should be clear and set at the beginning of the project to ensure that they are attainable and will be met.
- Proper documentation is very important, and records should show that the sustainability goals are being achieved.
- Resiliency and design planning for the future is also a very important to consider at the outset of the project.
- Use an already established sustainable rating system that is customizable like Envision,
- Local pollution control, biodiversity, and ecosystem preservation/enhancement, enabling of low carbon mass transit
- Allow for local innovation points, as environmental concerns can have very local origins

- Allow localities to capitalize on their local issues of environmental importance
- Gross vehicle miles traveled
- Measure the success of meeting stated goals
- Quality of product, life cycle cost to deliver, level of effort as measured against peers, efficiency of system, satisfaction of stakeholders/community, safety

Second, the respondents expressed their opinions on how to improve sustainability for California infrastructure construction projects, as follows:

- All infrastructure industries should consider reductions in embodied energy by implementing sustainable procurement practices such as requiring Environmental Product Declarations for construction materials
- Funding dedicated to sustainable project implementation would help make this a reality
- It is important to be able to evaluate sustainability and resiliency throughout each of the project phases
- Incorporate a sustainability management plan to track an individual project's specific approach and sustainability objects
- Follow one standard rating system
- The industry has become very siloed in terms of skills. The planning, environmental, design and construction experts are not well integrated. Without better cross expertise education many of us don't even know which questions we should be asking, let alone be able to integrate new ideas into our projects
- Rather than creating another sustainability rating system, that projects, companies, and/or the industry need to settle on one system. Having separate state-specific rating systems can cause discrepancies and quality control issues between projects. A single, all-encompassing rating system would allow projects to be equally assessed and result in consistent quality and resiliency
- We don't need another rating system. Use an already established one that is customizable like Envision, Primarily, road expansion projects should be recognized as fundamentally unsustainable
- Developing a system to ensure the sustainability of fundamentally unsustainable projects will ultimately get us nowhere

- Mass transit and ped/bike infrastructure investment is essential
- All infrastructure should serve multiple purposes. A roadway or bridge needs to also provide open space for flora and fauna, or park space for residents.
- Single use expenditures for infrastructure are not a sustainable approach
- De-prioritize projects that will induce demand and lead to more driving and GHG emissions
- Set realistic goals not driven by politics, train more staff on sustainability, create synergies between municipalities, promote/publicize achievements to the public, prioritize sustainability in the planning phase.

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About the Authors

Joseph J. Kim

Dr. Joseph J. Kim, P.E. (PI), is a Professor in the Department of Civil Engineering and Construction Engineering Management at California State University Long Beach. He was responsible for overall project coordination, assuring successful project completion, and preparing the final report.

Patricia McCarthy

Patricia McCarthy, P.E., is a civil engineering graduate student at the Department of Civil Engineering and Construction Engineering Management at California State University Long Beach who contributed to accomplishing the goals of this research project. Her interests within the field include construction engineering and sustainable project management. The scope of her work includes assistance with the design of the survey form, collection and analysis of survey data, and preparation of the MTI report.

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