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Tools to Prioritize Construction Phase Sustainability Actions (CPSAs) and to Measure CPSAs Implementation

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***Abstract:** Achieving sustainability targets on construction projects has increasingly become one of the prime strategies for construction organizations. To provide more detailed guidance on sustainability implementation on projects, Construction Industry Institute (CII) Research Team (RT) 304 developed a catalog of the Construction Phase Sustainability Actions (CPSAs). The primary objective of this paper was the development of two support tools, the CPSA Screening Tool and the CPSA Implementation Index, that could be used to enable efficient application of CPSAs, support sustainability-related decisions, and measure CPSA implementation and performance. The authors developed the tools in four stages: conceptual, detailed planning, tool programming, and testing. The tools were then demonstrated on a capital project to confirm their efficacy and applicability. This paper presents the background, inputs and outputs, and the algorithms of each tool. The CPSA Screening Tool can prioritize the CPSAs most relevant to a project; the CPSA Implementation Index enables continuous monitoring of implementation levels.*

Keywords: Construction Sustainability, Sustainability Actions, Screening Tool, Implementation Index

I. INTRODUCTION

As attention to the construction sustainability of capital projects has increased, many studies have been conducted on construction sustainability and a number of sustainability rating systems have been developed [1, 2, 3 and 4]. However, most of the previous sustainability research has focused on the planning and design phases of projects, the selection of onsite construction equipment, or the material characteristics [5 and 6]. The Construction Industry Institute (CII) initiated Research Team (RT) 304, *Sustainability Practices and Metrics for the Construction Phase of Capital Projects*, to investigate approaches to increase sustainability during the construction phase. To achieve the research objectives, the CII RT 304 first defined two key terms related to construction sustainability. The first term is *Construction Sustainability*, which is defined as the processes, decisions, and actions during the construction phase of capital projects that enhance current and future environmental, social, and economic needs, while considering project safety, quality, cost, and schedule [1]. The next term is the *Construction Phase*, which is defined as all fabrication/jobsite/field activities and decisions, starting with construction/fabrication contracting and planning for site mobilization, and continuing through to initial operations, final performance testing, and handover of the completed facility [1]. As an outcome of the research, RT 304 developed 54 Construction Phase Sustainability Actions (CPSAs) to provide more practical guidance on construction sustainability [1 and 2]. This paper highlights two Microsoft® Excel®-based tools that the team developed to support CPSA implementation: the CPSA Screening Tool and the CPSA Implementation Index. The CPSA Screening Tool prioritizes the CPSAs most relevant to a specific project, while the CPSA Implementation Index measures the levels of CPSA implementation.

A. Screening and Prioritizing CPSAs for Implementation on Projects

Because every construction project is unique and all projects have different sustainability goals, not all 54 CPSAs will apply to every project. Thus, project teams should discuss and select the most appropriate CPSAs for their particular projects. To enable this customization, the authors developed the CPSA Screening Tool to prioritize CPSAs according to a project's sustainability objectives and project conditions. Once it has selected and ranked a project's most relevant CPSAs, the tool provides automatic links to the CPSAs' corresponding catalog pages. The tool's inputs, prioritization algorithms, and outputs are discussed in a subsequent section of this paper.

B. Measuring the Breadth and Extent of CPSA Implementation

One of the objectives of this research project was to develop recommended input and output metrics pertaining to construction sustainability. With such metrics, project teams would be able to evaluate the levels of their

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construction sustainability implementation efforts and/or the impacts of these efforts against defined targets. The authors developed the CPSA Implementation Index as a sustainability input metric to measure the breadth and extent of implementation of the 54 CPSAs. A later section of this paper presents a detailed discussion of the inputs, the algorithm, and the outputs of the Implementation Index.

C. Scope and Objectives

The authors limited the research scope to sustainability actions which are executed during the construction phase of capital projects. The construction phase begins when the project site is mobilized and ends when a final commissioning report is issued by the construction manager for the owner or contractor. Example of activities during the construction phase includes the construction of temporary facilities and the project site management. The objectives of this research were (1) to develop a tool to prioritize and screen for high-impact sustainability actions that are most relevant to the project objectives, (2) to provide input and output metrics to assess the level of sustainability implementation, (3) to validate the developed tools, and (4) to identify issues for future research.

II. Prior Studies

This section presents a summary of common sustainability models, along with the categories of output metrics, all drawn from the available literature.

A. Common Sustainability Models

Many previous researchers have identified sustainability models that combine social, environmental, and economic aspects [7, 8, 9, 10, and 11]. Willard [12] analogized the triple bottom line of sustainability model—economic prosperity, environmental stewardship, and social responsibility—to a three-legged stool. This model requires that three parameters, the legs of the stool, must be balanced to support sustainability; otherwise the stool will be unstable and the sustainability effort will be ineffective. The elements of economic prosperity are good jobs, fair wages, security, infrastructure, and fair trade; the elements of environmental stewardship are reduction or elimination of pollution and waste, use of renewable energy, and the conservation and restoration of resources; and the elements of social responsibilities are working conditions, health services, education services, community and cultural well-being, and social justice [12]. Adams [13] suggested a sustainability model with economic measures, environmental measures, and social measures configured as three overlapping contiguous circles. This interlocking circle model indicates the three measures need to be better integrated and balanced. The last sustainability model examined by the authors was Cato's "three-circle model" with the environmental, social, and economic aspects presented as three concentric circles [14]. Unlike the Adams' model, Cato's model reflects reality insofar as it captures the interrelatedness of the economy, society, and the environment [14].

B. Sustainability during Construction Phase

Rodríguez López and Fernández Sánchez [9] concluded that, as sustainability has become fundamental criteria for construction projects, various methods have been increasingly used to measure construction sustainability and to promote project stakeholders' interest about impacts on the environment, society, and economic. Many sustainability assessment models are widely used to assess the level of sustainability during the construction phase, such as the Leadership in Energy and Environmental Design (LEED) or the Global Sustainability Assessment System (GSAS). The LEED [15] evaluates the sustainability with a checklist of LEED criteria and provides a framework for project stakeholders to identify and assess practical sustainability strategies. Moreover, the GSAS [16] is the expansion of the Qatar Sustainability Assessment System (QSAS), which is a widely applied sustainability assessment system in the Middle East and North Africa (MENA) region used to consider environmental impacts and local community needs.

To efficiently implement the sustainability rating systems during the construction phase, drivers were identified that influence the implementation of sustainability. These drivers include project stakeholders' requirements in design/construction, government legislations and international standards, public knowledge and interest of sustainability issues, use of sustainability as a marketing strategy, and advances in green building technologies and materials [17]. The barriers to implement the construction sustainability also were identified to mitigate any negative impact by the sustainability implementation and include high initial costs, fear of change with regards to requirements to quickly complete projects, lack of general knowledge/awareness and insufficient research in sustainable construction, lack of guidelines and precedents for implementation and performance assessment, and communication issues between construction trades [17].

Despite recognition of the importance of sustainability during the construction phase, there were very few effective assessment indicators available to evaluate a construction project's sustainability [18 and 19]. Therefore, the authors have developed an assessment tool by incorporating economics, environmental stewardship, and social progress into its tool to enhance construction sustainability during the construction phase.

III. CPSA Screening Tool

A. Need and Purpose of the Tool

Project managers might have difficulty selecting appropriate and relevant CPSAs for construction sustainability implementation from a catalog of 54 CPSAs [1 and 2]. To help users sort and rank such a large number of possibilities, the authors developed a spreadsheet-based screening tool for optimal sustainability implementation on their projects. With this tool, a project manager can select the most applicable CPSAs to maximize project performance.

B. *Tool Development*

The CPSA Screening Tool was developed in four different stages: (1) conceptual; (2) detailed planning; (3) tool programming; and (4) testing/modifying.

During the conceptual stage of the tool development, the authors identified and developed inputs, logic and an algorithm, and outputs for the tool. The final inputs would be project-specific sustainability priorities, i.e., project economics, environmental stewardship, social progress, and project characteristics. The outputs for the screening tool would be a prioritized (ranked) list of CPSAs, based on the computation of a Relevance Index (RI) to be determined by a user's input. The team decided to base the screening tool on Excel® software since it is widely used in the construction industry. The detailed descriptions of the tool logic and algorithm are presented in subsequent sections.

During the detailed planning stage, the authors used the Excel® software's functions to structure the tool's two major tabs: the resident database tab and the interface tab. The resident database tab contains three fixed data sets: (1) the relevant CPSA catalog entry fields; (2) the leveraging project conditions; and (3) scoring models with user inputs for project-specific sustainability priorities. The tool uses these three data sets for the RI computation. The tool also contains five interface tabs: (1) the Introduction tab; (2) the User Guide tab; (3) the Input-Sustainability Priorities tab (See Figure 1); (4) the Input-Project Conditions tab (See Figure 2); and (5) the Output-Screening Results tab (See Figure 3).

After determining the detailed characteristics and structures of the tool, the authors proceeded with programming. The team incorporated the necessary information from each CPSA catalog sheet into the tool's spreadsheet matrix format and then programmed the computational algorithm and scoring models. Once the programming was complete, the interface tabs were finalized with functional features such as "Back" and "Next" buttons.

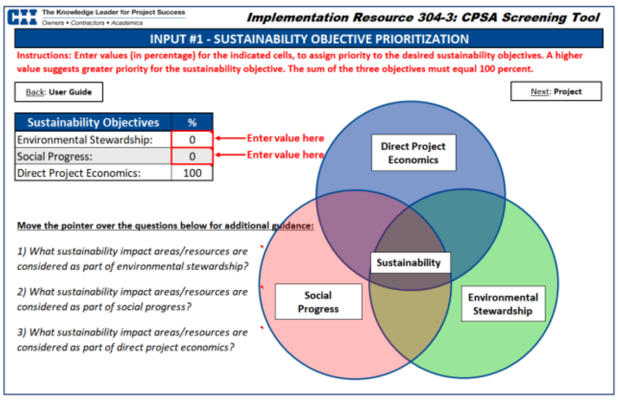


FIGURE I
Screenshot of "Sustainability Objective Prioritization" Tab

Then, the prototype of the screening tool was distributed to the research team for internal testing and debugging. The CPSA Screening Tool was then modified in response to their comments. Lastly, the tool was demonstrated on a capital construction project and was validated by the 33 external validation reviewers.

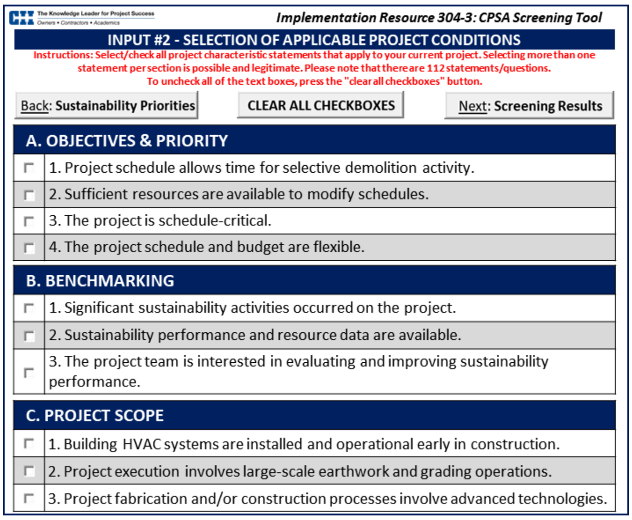


FIGURE II
Partial Screenshot of "Project Conditions" Tab

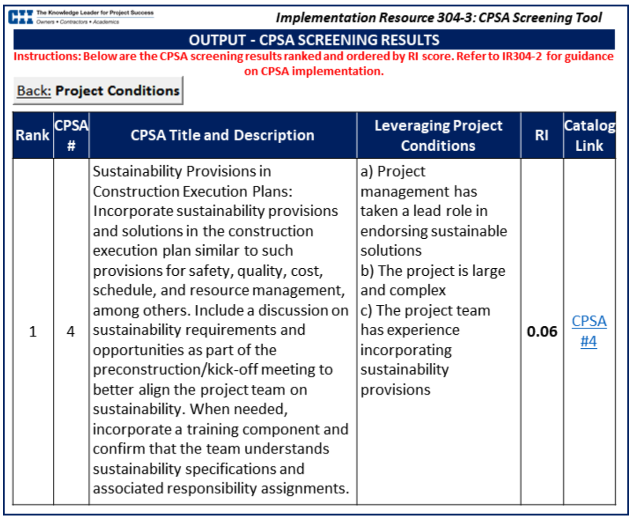


FIGURE III
Partial Screenshot of "CPSA Screening Results" Tab

C. *Tool Inputs and Outputs*

The CPSA Screening Tool (See Figure 1) collects user inputs to determine a project's economic, environmental and social sustainability priorities. It also asks the user to answer a series of Yes/No questions pertaining to project characteristics (See Figure 2), and then converts the responses to values of 0 and 1 for the RI computation. The tool presents the final prioritized list of CPSAs in a tabular format, ranking them from highest to lowest RI and including other information such as a CPSA title, a CPSA description, leveraging project conditions, and a hyperlink to the corresponding CPSA catalog sheet. (See Figure 3 for a screenshot of the output tab and O'Connor et al. [1] for the entire list of the CPSA catalog.)

The CPSA catalog identified the primary impact areas, i.e., environmental, social, and economic, most affected areas/resources, and impact magnitude for the primary impact. Examples of the most affected areas/resources for the environmental area are energy consumption, greenhouse gases, indoor air quality, water consumption, water quality, waste generation, land use, noise, pollution, odors, or light pollution; for the social area include health and safety, community relationships, local resources depletion, community infrastructure, traffic, or jobs created; and the economic area consists of project fiscal impacts [1 and 2]. Users are able to estimate the related magnitude of the environmental, social, and economical impact of each prioritized CPSA from the corresponding CPSA catalog sheet.

D. Algorithm

The prioritized list of CPSAs generated by the tool is ranked according to the RI value of each CPSA—the weighted composite value of its applicability to the user's project-specific sustainability priorities and project characteristics. (See Equation 1 for the RI computation of each CPSA and Figure 4 for the process.)

Relevance Index (RI) = Impact Score (IS) X Conditions Score (CS) - Eq. (1)

where, IS = (PSP X SIR)
PSP: Project-specific Sustainability Priorities
SIR: Sustainability Impact Rating

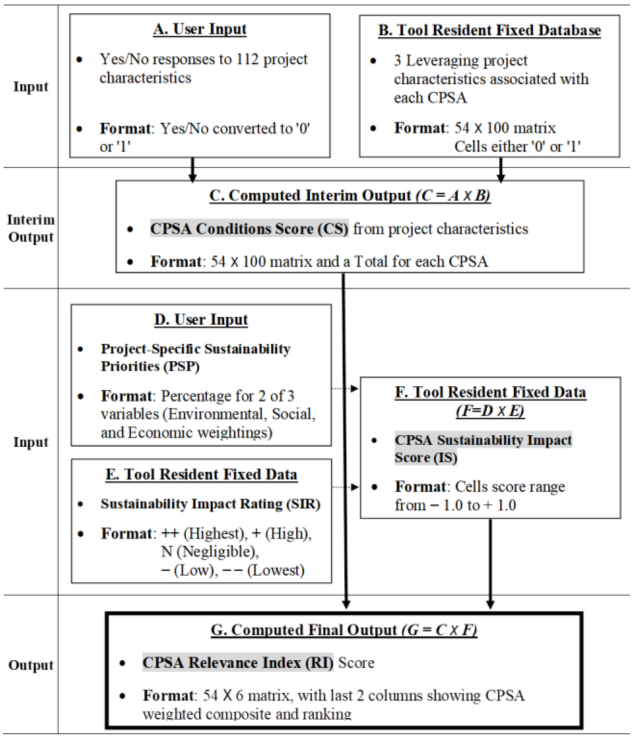


FIGURE IV
Process of CPSA Screening Tool

The RI comprises two components: the Impact Score (IS) and the Conditions Score (CS). The IS is the Project-specific Sustainability Priorities (PSP) multiplied by the Sustainability Impact Rating (SIR). The user-generated PSP values reflect the respective percentages of project's economic, environmental, and social sustainability priorities, which together sum up to 100 percent. The estimated SIR magnitudes within specific environmental, social, and economic parameters were assessed through research team deliberations. A detailed description of this model is as follows: 1) a rating of **"+"** suggests that the implementation of the CPSA will have a positive influence on the respective primary impacts; 2) a rating of **"–"** indicates that the implementation of the CPSA will likely have a negative influence on the respective primary impacts; 3) a rating of **"+ +"** or **"– –"** places emphasis on CPSAs with significant positive or negative influences on the respective primary impacts; and 4) a rating of **"N"** signifies that respective primary impacts are minimal or negligible [1]. The initial SIR magnitudes for all CPSA implementation were **"U"** ratings, which means the impacts are unknown and could result in either positive or negative impact based on project conditions. Then the SIR magnitudes for **"U"** ratings were further assessed and revised until all research team members agreed on one of the other five sustainability ratings. Table 1 presents the SIR scoring model.

TABLE I
SIR scale

Condition	SIR scale
If the SIR is ++	1.00
If the SIR is +	0.60
If the SIR is **N**	0.00
If the SIR is −	- 0.60
If the SIR is − −	- 1.00

For each CPSA, the Conditions Score (CS) compares the user's project characteristics to each of three project conditions that leverage benefits from its implementation. Table 2 shows the linear scoring model of the CS. The scoring models for both SIR and CS are stored in the screening tool for the RI computation.

TABLE II
The linear scoring model of the Conditions Score

The leveraging condition	Point
If 0 out of 3 CPSA leveraging conditions apply to the user's project characteristics	0.00
If 1 out of 3 CPSA leveraging conditions apply to the user's project characteristics	0.33
If 2 out of 3 CPSA leveraging conditions apply to the user's project characteristics	0.67
If 3 out of 3 CPSA leveraging conditions apply to the user's project characteristics	1.00

E. Tool Demonstration and Validation

The developed CPSA Screening tool was reviewed by the research team members for internal testing and debugging. Then, the modified Screening tool was validated by six external subject-matter experts (SMEs). Lastly, the tool was demonstrated on very large Mexico mining project.

The external SMEs for both the CPSA Screening tool and the Implementation Index had an average of 29 years (175 cumulative years in total) in the area of construction sustainability or construction management from owner and contractor organizations. The questionnaires on the validation feedback form contain two sections: 1) background information of an expert including years of industry experience and current job titles; and 2) feedback comments and markups after the tool application. According to the feedback comments, the computational algorithm of the tool was modified due to a ranking function error. Before the modification, the tool used the user inputs to compute the Relevant Index (RI) and then list the CPSAs from the highest to the lowest RI score. However, if two or more CPSAs had the same RI score, the screening tool returned an error message. This error has been fixed and the screening tool presents the list of CPSAs ranked by the RI score.

The revised tool was demonstrated on the Mexico mining project. The mine operator company is one of the major iron ore producers in North America (including Mexico). In 2013, it produced iron ore concentrates, pellets, lump, and fines totaling approximately 7 million metric tons. After application of the tool, the personnel from that project provided highly positive feedback and validated both the usefulness and ease of application of the tool. The objective of the CPSA Screening Tool is prioritization of the relevant CPSAs for the construction sustainability implementation. However, the project personnel couldn't provide any quantitative results from their CPSA Screening tool demonstration.

IV. CPSA Implementation Index

A. Need and Purpose of the Tool

From time to time, a project team needs to measure a project's sustainability performance with objective metrics. To meet the primary research objective to develop construction sustainability metric, the authors developed the CPSA Implementation Index, a tool that helps project teams measure the breadth and extent of their implementation of the 54 CPSAs or their performance in terms of their construction sustainability goals.

B. Tool Development

To construct the CPSA Implementation Index, the authors used the same four-stage process used to develop the CPSA Screening Tool: (1) conceptual; (2) detailed planning; (3) tool programming; and (4) testing/modifying.

During the conceptual phase, the team identified an input, an output, and an algorithm for the tool. With a catalog of 54 CPSAs [1 and 2], the finalized CPSA Implementation Index would measure the extent of an individual CPSA implementation on a project with a numerical score ranging from 0 to 1.85 points. The detailed description of the CPSA Implementation Index computation can be found in the following *D. Algorithm* and *E. Tool Demonstration and Validation* section. The total number of possible points is 100 (54 times 1.85); therefore, if all CPSAs were implemented at the highest level, the index score would be 100.

Once the inputs and outputs had been confirmed, the team entered the detailed planning phase and began structuring the index. Like the CPSA Screening Tool, the index tool consists of five interface tabs: (1) the Introduction tab; (2) the User Guide tab; (3) the Project Information tab; (4) the Input-Implementation Effort tab; and (5) the Output-Implementation Index tab. (See Figure 5.) The tool also has an embedded database and was developed in Excel® software for convenient accessibility. The first two tabs introduce the CPSAs and give instructions for using the index tool. The third tab, the Project Information tab, queries basic project information for record-keeping purposes. The inputs to this tab have no impact on the index score. The input score is calculated on Input-Implementation Effort tab. Finally, the Output-Implementation Index tab provides the index score of a project's levels of CPSA implementation.

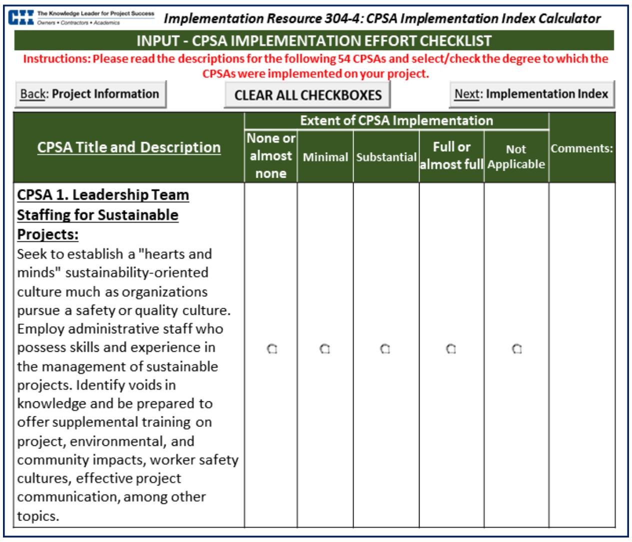


FIGURE V

Partial Screenshot of "CPSA Implementation Effort Checklist" Tab

After the completion of the detailed planning phase, the authors initiated the programming phase. In this phase, the team extracted relevant information from each CPSA sheet in the catalog, incorporated this information into a spreadsheet-based matrix, and programmed a computational mechanism and scoring models in the tool's resident database. Additional features such as "Back" and "Next" buttons, and pop-up messages to provide instructions were added to the tool.

Finally, the CPSA Implementation Index was distributed to the research team to evaluate the tool's clarity, functionality, and accuracy. The CPSA Implementation Index was modified to address the most relevant comments from this internal review.

C. Tool Inputs and Outputs

In order to evaluate sustainability implementation efforts and/or to gauge performance against defined project sustainability targets, the index tool's input-oriented and output-oriented metrics were developed. The input metrics measure the breadth and extent of implementation efforts against an established sustainability goal, while the output metrics focus only on the actual achievement of one or more performance goals by assessing sustainability performance.

The CPSA Implementation Index calculator tool computes the index score based on user's input relevant to his/her project-specific sustainability implementation of individual CPSAs among the following options: 1) None or almost no implementation; 2) Some or partial implementation; 3) Substantial partial implementation; and 4) Full or almost complete implementation [1]. Beyond this information, the tool uses the Implementation Index score that is described in the *D. Algorithm* section. The CPSA Implementation Index enables a user to assess sustainability implementation progress over time.

The authors identified two practical output metrics for each of the 54 CPSAs. As a supplement to the CPSA Implementation Index tool, the output metrics will provide insight into how effectively goals were achieved against one or more specific performance goals during the construction phase. Figure 6 illustrates the number of output metrics per category. Table 3 presents a detailed list of the output metrics by category. Among the nine categories associated with the performance measurement, *Environmental Footprint* and *Construction & Demolition Waste* were the most common categories of the output metric, accounting for 35 percent of all 108 output metrics (two metrics times 54 CPSAs). The other categories are *Contracting & Procurement, Benchmarking, Community or User Satisfaction, Equipment, Work Processes, Labor & Staff, and Facility Commissioning*.

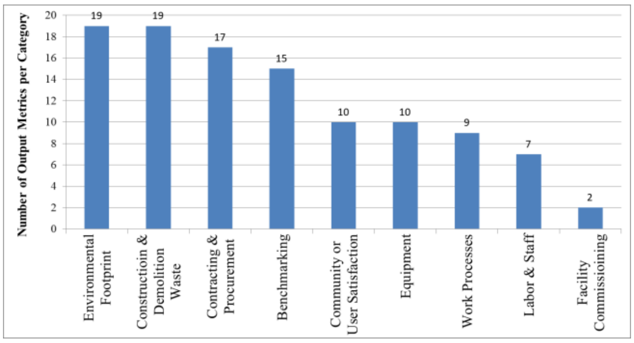


FIGURE VI
Categories of Output Metrics

TABLE III
Construction Sustainability Output Metrics

Item #	Category of Metric	CPSA #	Output Metric
1	**Benchmarking**	1, 4, 10, 54	Percentage of projects with a sustainability performance section in project reports
2		1, 54	Percentage of projects that document sustainability lessons learned
3		3, 10	Project-over-project or year-over-year comparison of one or more specific sustainability metrics
4		5, 26	Portion of sustainability risks that are effectively mitigated
5		5	Cost and/or schedule savings from sustainability risk avoidance or mitigation
6		7	Periodic traffic counts on major arterials near the jobsite
7		13, 17	Contractor safety performance vs. target
8		26	Time impact on project schedule
9	**Contracting & Procurement**	4, 53	Contract requirement that sustainability be included in the project execution plan
10		11	Percent of corporate purchases that consider sustainability claims in the prequalification process
11		11	Percent of suppliers and vendors that have at least one sustainability certification
12		12, 15	Sustainability change proposal clause (similar to Value Engineering) is included in the prime contract
13		12	Sustainability objectives are stated in the prime contract
14		14	Dollar value of MBE/ WBE/SBEs contracts
15		14	MBE/WBE/SBE contracts as a percent of all contracts
16		16, 39, 41	Change in local employment from project (percent or number)
17		18	Proportion of delivery arrivals during peak traffic hours
18		41	Contribution of project to local tax revenue
19		43, 50	Cycle time from material request to material site delivery
20		49	Proportion of truck deliveries that are at or near full capacity
21	**Work Processes**	3	Number of annual awards for sustainability contributions
22		8	Percent of craft work hours performed in night shift
23		9	Approximate number of hard-copy documents (pages) transferred to owner at final handover
24		9	Percent of project documentation managed electronically
25		13	Percent of project contracts that incorporate sustainability issues as a part of contractor prequalification
26		25, 32, 44, 45	Cost savings
27	**Construction & Demolition Waste**	17, 22, 24, 25, 36, 37, 42, 44, 45, 46	Portion or volume of total waste recycled or diverted from a landfill
28		22, 24, 42, 46	Street value of recycled material
29		23	Earthwork quantity reduced or eliminated
30		34, 52	Quantity of gray water reused
31		36, 37	Reduction in landfill tipping fees

Item #	Category of Metric	CPSA #	Output Metric
32	Labor & Staff	16	Field productivity
33		29, 39	Effort or resources required to reach employment targets (per hired craft worker or PM staff)
34		29	Level of satisfaction of workers living in project camp
35		38, 40	Local workforce turnover rate
36		38	Number of labor skill certifications awarded annually
37	Equipment	23, 43, 47, 51	Equipment environmental performance
38		47, 48	Fuel consumption efficiency
39		48	Change in equipment rental expense
40		49	Equipment capacity utilization
41		50	Amount of vehicle idling
42		51	Equipment inspection frequency
43	Facility Commissioning	33	HVAC testing performance
44		53	Commissioning resource efficiency
45	Environmental Footprint	8	Percent of jobsite electricity from renewable sources
46		15, 20	Number of changes/substitutions to environmentally friendly materials
47		18, 35	Local air quality metrics
48		19, 27, 28	Proportion of sensitive vegetation not impacted from project
49		19, 27	Number of significant trees impacted from project
50		20, 28, 30, 31	Size of carbon footprint from project
51		21	Reduction in measured noise level
52		30	Amount of particulate matter from site power sources
53		31	Power consumption per basis unit ($K of construction, K work hours, etc.)
54		33	Indoor air quality test results
55		34	Reduction in consumption of potable water
56	Community or User Satisfaction	2, 6	Percent of community issues addressed
57		2, 6	Percentage of stakeholder engagement plan that is implemented
58		7, 21, 35, 40, 52	Number of complaints from community, agency, or camp residents
59		32	Facility user satisfaction level

D. Algorithm

The CPSA Implementation Index generates a numerical index score (from a total possible 100 points) of the breadth and extent of construction sustainability implementation of the 54 CPSAs. Table 4 presents the scoring points and the description of the extent of CPSA implementations. The authors allocated 1.85 points per CPSA implementation by distributing 100 points (the total score) among the 54 CPSAs. The descending values of 1.23, 0.62, and 0.00 represent the linear distribution of points at incrementally lower implementation levels. Thus, the implementation levels of all 54 CPSAs equally account for the CPSA Implementation Index score.

TABLE IV
Scoring points for CPSA Implementation Index

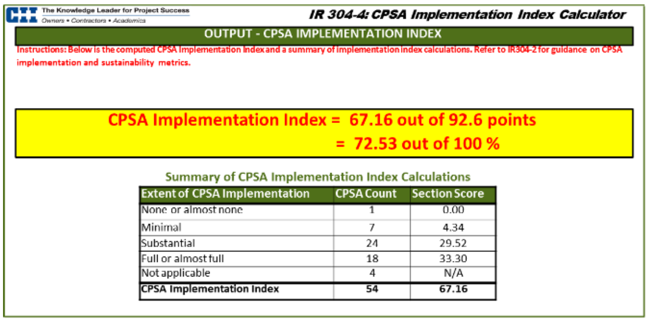
Extent of Individual CPSA Implementation	Point
None or almost no implementation (less than 20 percent complete)	0.00
Some or partial implementation (between 20 and 50 percent complete)	0.62
Substantial partial implementation (between 50 and 80 percent complete)	1.23
Full or almost complete implementation (more than 80 percent complete)	1.85

E. Tool Demonstration and Validation

The authors conducted a trial test of the CPSA Implementation Index by the external SMEs for the CPSA Screening tool that is described in the *Section III. E. Tool Demonstration and Validation*. From the tool demonstration and validation, the authors were able to assess its efficacy and applicability on construction projects.

Similar to the CPSA Screening tool, the CPSA Implementation Index was reviewed and challenged by the six external SMEs. The experts provided valuable suggestions, and the authors used their feedback to revise the tool. One modification was to add the Input – "Project Information" tab after the "User Guide" tab. Another change was to add the *Not Applicable* response for the extent of CPSA Implementation on the "Input - CPSA Implementation Effort checklist," since some CPSAs might never be considered for certain types of projects; for instance, small projects in urban settings would never implement CPSA No. 29, *Sustainable Temporary Worker Camps* [1].

This demonstration was conducted on a large U.S. urban rail transit project midway through construction. This project involved a public-private partnership delivery method with capital funding of 2.2 billion and a 40.2-mile (in total) electric commuter rail corridor. The CPSA Implementation Index score for the urban rail transit demonstration was 72.53 percent. As shown in Figure 7, the case project has one *None CPSA Implementation or Not Applicable* (a scoring point: 0.00), seven *Minimal extent of CPSA Implementation* (a scoring point: 0.63), 24 *Substantial extent of CPSA Implementation* (a scoring point: 1.27), and 18 *Full extent of CPSA Implementation* (a scoring point: 1.85).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IR 304-4: CPSA Implementation Index Calculator

OUTPUT - CPSA IMPLEMENTATION INDEX

Instructions: Below is the computed CPSA Implementation Index and a summary of implementation index calculations. Refer to IR304-2 for guidance on CPSA implementation and sustainability metrics.

CPSA Implementation Index = 67.16 out of 92.6 points
= 72.53 out of 100 %

Summary of CPSA Implementation Index Calculations

Extent of CPSA Implementation	CPSA Count	Section Score
None or almost none	1	0.00
Minimal	7	4.34
Substantial	24	29.52
Full or almost full	18	33.30
Not applicable	4	N/A
CPSA Implementation Index	**54**	**67.16**

FIGURE VII
Current Level of CPSA Implementation Index (72.53 percent)

From the CPSA Implementation Index tool validations and demonstration, the authors concluded that capital project stakeholders are able to assess their sustainability implementation level using this tool. If they periodically evaluate sustainability implementation, the implementation effort and progress over time can be tracked and proactively mitigate any potential issues in terms of construction sustainability.

V. Conclusions and Recommendations

Many capital project stakeholders including owners, contractors, and subcontractors have been seeking more detailed and practical guidance to implement sustainability activities during the construction phase. This paper introduces two implementation tools, the CPSA Screening Tool and the CPSA Implementation Index developed by the Construction Industry Institute (CII) Research Team (RT) 304.

Both the CPSA Screening Tool and the CPSA Implementation Index were developed in four different stages: 1) conceptual, 2) detailed planning, 3) tool programming, and 4) testing/modifying. During the conceptual stage of each tool development, the authors identified inputs and outputs and developed logic and algorithms. During the detailed planning stage of the tools, the authors used the Excel® software's VBA functions to structure the tool's major tabs for input, output, and the resident database tab. Then the team incorporated the necessary information from the 54 CPSA catalog and programmed the computational algorithm and scoring models. Lastly, during the testing/modifying stage, the developed tools were distributed to the research team members for the internal testing, which was then demonstrated on a capital construction project as well as validated by the 33 external validation reviewers.

It is important to note that this paper provides detailed practical guidance on construction sustainability implementation based on their project characteristics and sustainability priorities. A few previous research studies focused on construction sustainability during the construction phase, while others focused on the design or operations & maintenance (O&M) phase. The first contribution of this study is the development of the *CPSA Screening Tool*. The Screening tool enables construction project teams to determine which CPSAs are the most applicable and relevant to their projects. The tool ranks all 54 CPSAs on the basis of Relevance Index (RI) score. The RI is a weighted composite value of the applicability of the CPSAs to the user's project characteristics and sustainability priorities. The second contribution of this study is the development of the *CPSA Implementation Index Tool*. The Implementation Index tool generates input oriented sustainability metrics for sustainability implementation during the construction phase and is the tool that assists project teams in measuring their levels of CPSA implementation and evaluating project performance against sustainability targets. The last contribution of this study is the demonstration on a capital construction project in order to test the applicability of the two tools.

The authors recommend additional future research forward on more applications of both the CPSA Screening Tool and the CPSA Implementation Index. These should provide more insight into current levels of individual CPSA implementation and help gauge overall industry perception of construction sustainability practices.

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