Continuous Value Enhancement Process

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Abstract: The demand for sustainable buildings is an important emerging trend in the building industry. However, the task of delivering these facilities is more difficult than for traditional projects and existing project management techniques struggle to handle the high levels of complexity present. A process-based model, called the continuous value enhancement process (CVEP), was developed to systematically generate and evaluate project alternatives leading to high performance solutions that improve project performance and increase levels of sustainability. Developed specifically to address the challenges facing the Pentagon renovation—which will become the world's largest green office renovation—CVEP is tested to research its ability to support project management decision making in ways that elevate sustainability and project performance. The key contributions of this model include the integration of sustainable objectives into project management practices, and the development of a metric for measuring the quality and focus of project team decisions.

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Introduction

The demand for high performance, "green" or sustainable buildings is rapidly emerging as a significant trend in the building industry. Attracted by improved energy efficiency, lower resource consumption, as well as healthier and more productive indoor environments, both private and public owners are turning to high performance buildings to meet their capital facility needs.

The task of delivering high performance facilities is often more difficult than for traditional projects and existing project management techniques struggle to handle the high levels of complexity present. For example, the integrated design process of high performance buildings requires intensely close team interaction in order to size building systems correctly and take advantage of system synergies. Yet, sustainable objectives are treated on many projects as "tack ons" to normal project management requirements and managed separately. This often leads to inefficiencies in the delivery process that inhibit many cost-saving opportunities from being realized, which in turn leads to increased capital costs.

Constructability reviews are one technique that project managers use to enhance project delivery efficiencies and realize cost savings. The analyses of constructability issues during design can improve project decisions and enhance facility value by simplifying the design to reduce field labor, lower material waste, improve safety, and streamline construction sequences. Several practices for formally managing constructability knowledge during project design have been developed.

Drawing on the established capabilities of constructability, the continuous value enhancement process (CVEP) was developed as a project management tool to weave sustainable objectives into normal project execution. Responding directly to the challenges facing the Pentagon renovation, CVEP was experimentally implemented in the project management of this large and very challenging sustainable project. The ability of CVEP to support project management decision making in ways that elevate sustainability and project performance is analyzed in this paper.

Objective

The objective of this paper is to integrate sustainable objectives into project management practices by developing a process-based model for detailing project decisions concerning sustainability on high performance building projects. This will enable project teams to continuously and systematically generate new ideas and identify optimal high performance building solutions. These superior decisions create improvements to both project performance (constructability-related attributes) and levels of building sustainability.

Background

Integrated Design

Most significant gains in high performance sustainable buildings have been made through innovative and elegant design. Emphasizing reduced energy, lower resource consumption, and healthy and productive indoor environments, sustainable design in the building industry has made major advances to building performance. Integrated design (or whole building design) has been the

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focus of most research that integrates sustainable objectives into building projects. The design charrette is the main tool in the integrated design process. This meeting brings together different design disciplines to define the multiple project objectives, and optimize building systems with the natural systems in which they exist (Watson 1996; Mendler and Odell 2000; Reed 2002; Eisenberg and Reed 2003).

While a more difficult design process, integrated design elevates levels of design integration to optimally size building systems and components. The strength of integrated design is in obtaining early input from industry and discipline experts, and key stakeholders to the project (Mendler 2001; Reed 2002; Eisenberg and Reed 2003). Yet, little research has been performed to increase sustainability input after design and during construction, especially from those members of the project team managing and performing the work. The literature primarily focuses on ensuring sustainable attributes of the design are not compromised during construction (Kobet et al. 1999; Mendler and Odell 2000).

Construction Expertise in Sustainable Design

Riley et al. (2003) found that construction organizations can contribute to the success of sustainable projects in four areas: (1) estimating during design; (2) information on the use of sustainable building materials; (3) development and execution of plans for construction waste minimization and recycling; and (4) employing practices during construction to improve indoor air quality. Construction organizations clearly have valuable knowledge to contribute to sustainable design however, the methods to introduce this knowledge remain somewhat primitive. Current methods, such as design reviews, are crude, often inducing rework and animosity between designers and contractors (Arditi et al. 2002). Some have looked at using expert systems and databases with promising future potential (Fisher and Tatum 1997; Soibelman et al. 2003; Staub-French 2003). However, little research has been performed to improve how construction knowledge is used in design so that decisions are made right the first time (Horman 2000).

Constructability and Sustainability

A tangible way that many construction managers and contractors use to provide input in design is through constructability programs. Constructability is defined as the "optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives" (CII 1986). Research efforts have demonstrated that when systematically implemented, constructability improvement efforts produced an average reduction in total project cost and schedule between 4.3 and 7.5%, respectively (CII 1993).

Building constructability is not widely associated with sustainability, but this relationship is starting to be explored for synergy and potential advantages. In fact, many project teams practice sustainability and constructability in ways that challenge each other, sometimes value engineering sustainable features out of a project in the name of cost optimization. However, recent research has found strong correlations between constructability and sustainability concepts as well as implementation processes (Pulaski and Horman 2003). Both sustainable design and constructability "strive for the efficient use of resources through the reduction of waste" (Pulaski et al. 2003b). More directly, these concepts have specific overlaps in their objectives, similarities in the ways they are managed in design (e.g., use of integrated organizational teams, mockups, design reviews, and lesson learned systems to manage additional requirements), connections in the integration of systems and materials, and even similar methods to deconstruction (demolition) (Pulaski et al. 2003a,b; Pulaski and Horman 2003), showed how constructability processes were used at the Pentagon to enhance project sustainability.

Sustainable or "Green" Value Engineering

Value engineering is another way to introduce construction knowledge in design. Value engineering is a rigorous and systematic effort to improve the value and optimize the life cycle cost of a facility (Green and Popper 1990; Dell'Isola 1997). This is a little broader in scope than constructability improvement efforts which focus on simplifying the construction process by removing unnecessarily difficult or impossible demands on the contractor (Soibelman et al. 2003). While the optimization of life cycle costs are important to sustainability, many other issues such as the selection of environmentally preferable materials, enhanced indoor environmental quality, and waste reduction are typically not emphasized, and therefore rarely considered.

When done correctly, green value engineering can be very effective. For instance, the Federal Facilities Council (2001) developed a process for integrating value engineering, life cycle costing, and sustainability and were able to save of $30 million on the EPA Campus at Research Triangle Park, North Carolina (Mendler 2001). The ability to achieve first cost savings while explicitly addressing long term (sustainable) performance goals is a very important capability currently missing on many sustainable facility projects where project budgets increase 2.5–7% to accommodate sustainability (Smith 2003).

Like constructability reviews, however, value engineering tends to be used periodically on projects limiting its usefulness for project management and inducing wasteful redesign cycles. Austin and Thomson (1999) showed that frequent and detailed value engineering sessions are necessary after the very early phases of design due to increasing levels of detail.

Continuous Improvement Process

Although a number of construction companies have practiced one form of continuous improvement or another for many years, it was not really until the quality movement (i.e., quality assurance, total quality management, etc.) that the power of continuous improvement was realized. Highly visible successes in manufacturing, such as Toyota with their *kaizen*, showed how small incremental, but continual improvements can reap substantial benefits for the company. Forms of these practices are used in construction (Slaughter 1998; Powell 1999; Santos et al. 2000). The most successful of these programs are those where time is deliberately carved out of a worker's busy schedule to examine new opportunities for improvement (Spear and Bowen 1999). What is noticeable is their disciplined use of the "scientific method" to hypothesize and test potential improvements.

Continuous Value Enhancement Process

The CVEP is a project-level process for continuously extracting ideas from project team members and quickly assessing the impact of each potential solution on project performance and sustainable building objectives. This process-based model enables

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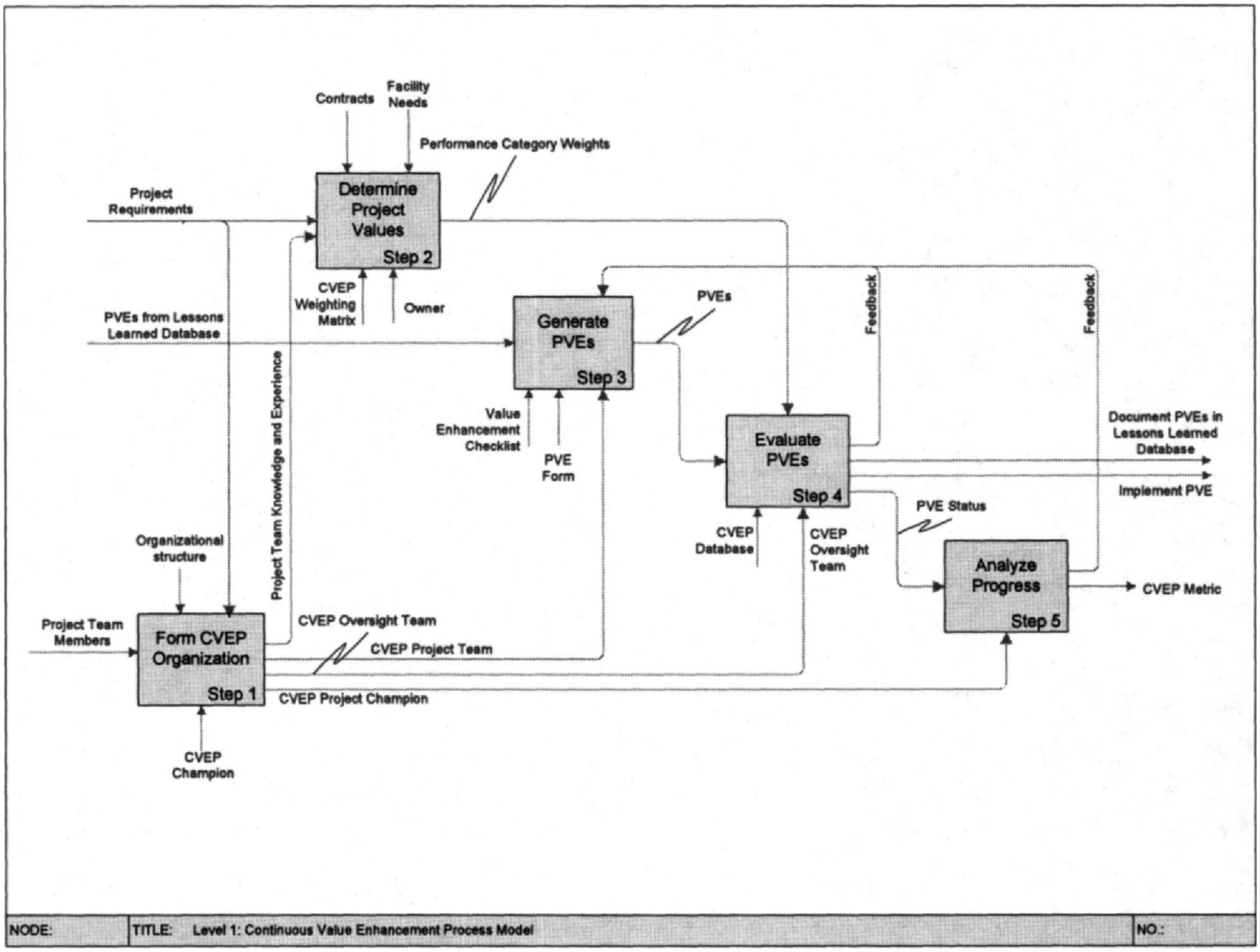

Fig. 1. Continuous value enhancement model

project teams to harness the knowledge and competencies of owners and construction professionals to generate high performance building solutions that are aligned with the owner's priorities. The CVEP is designed to coincide with existing project management tasks and responsibilities and has four functions:

1. Provide a systematic and comprehensive method to evaluate detailed project decisions against explicitly devised values established upfront for the project;
2. Continuously collect sustainable building solutions from throughout the project life cycle that improve project performance;
3. Identify significant project decisions and their appropriate timing for use on future projects; and
4. Produce new and innovative solutions.

The CVEP model possesses five steps, which are shown in IDEF0 format in Fig. 1. The inputs, outputs, mechanisms that perform the process (i.e., person, team, or tool), and controls (i.e., information) that influences the process are illustrated in the model.

Step 1: Form Continuous Value Enhancement Process Organization

The implementation of CVEP requires the formation of two teams (CVEP Project Team and CVEP Oversight Team) and one champion to coordinate all activities. The CVEP Project Team is responsible for generating ideas for improvement, termed potential value enhancements (PVEs). The CVEP Oversight Team is responsible for evaluating the PVEs developed by the CVEP Project Team. This team should have some independence of the CVEP Project Team and consist of a cross-disciplinary group of individuals which enables alternative perspectives to surface and be addressed.

Step 2: Determine Project Values

The project values or priorities are determined by the owner under the guidance of the CVEP organization using the CVEP weighting matrix. A sample is illustrated in Fig. 2. This paired comparison matrix evaluates the importance of one category at a time. If the category on the left is of greater importance than the category listed in the upper row, a value of one is assigned to the corresponding cell in the matrix. If the upper column is preferred, a value of zero is entered in the appropriate cell. The values are summed and weights determined. The weights are used in Step 4 to determine how closely aligned each PVE is with the project values.

Step 3: Generate Potential Value Enhancements

When the project begins the design development phase, the CVEP Project Team meets on a regular basis (i.e., once a month) to identify PVEs that can improve project performance and sustainable objectives. If the PVE is expected to perform better in a particular category than the industry standard or current practice a

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Determining Weight Factors										
Desired Performance Categories	Cost	Quality	Schedule	Process Efficiency	Safety/ Health	Maintainability	Resource Use	LEED Credit	Sum	Weight
Cost		1	0	0	0	0	1	1	3	0.107
Quality	0		0	0	1	0	1	1	3	0.107
Schedule	1	1		0	0	0	0	1	3	0.107
Process Efficiency	1	1	1		1	1	1	1	7	0.250
Safety/ Health	1	0	1	0		0	1	1	4	0.143
Maintainability	1	1	1	0	1		1	1	6	0.214
Resource Use	0	0	1	0	0	0		0	1	0.036
LEED Credit	0	0	0	0	0	0	1		1	0.036
								Total	28	1.000

Fig. 2. Sample continuous value enhancement process weighting matrix

positive (+) rating is assigned, and if the PVE is anticipated to perform worse a negative (−) rating is assigned. If they are equivalent (i.e., no change), a zero is assigned. This straightforward binomial rating scale was selected to expedite the evaluation process. Rough order of magnitude cost estimates are performed and the appropriate time to introduce this idea in the project is discussed and recorded in a database to provide guidance on future projects.

Step 4: Evaluate Potential Value Enhancements

On a regular basis (i.e., once a month) the CVEP Oversight Team evaluates the performance ratings, cost estimate, and timing of decision of each PVE for accuracy. Additionally they provide comments based on their expertise and perform further research if necessary. The weighted score is determined by multiplying the performance rating (+1, 0, or −1) by the weights assigned from the CVEP weighting matrix. Generally, scores greater than zero are favorable and should be implemented.

Step 5: Analyze Progress

The PVEs are entered into the CVEP metric and reported on a regular (i.e., monthly) basis to the project manager and senior management. The CVEP metric provides information about the focus and quality of PVEs generated by the project teams and also reports any project savings realized from implemented PVEs.

Rating System Categories

Eight categories are used for measuring project performance and sustainable building objectives. The purpose of the rating system is to draw specific attention to key performance aspects of the project that are important, but not typically considered in everyday decisions. The rating systems permits systematic and straightforward analysis without complex calculations which tend to prohibit the use of other decision-making tools in sustainable construction like life cycle analysis. Four of the eight categories represent project performance (cost, quality, schedule, process efficiency), while the remaining four represent sustainable building objectives [safety/health, maintainability, resources used, and leadership in energy and environmental design (LEED) credit]. Subsequent versions have used slightly different categories more suited to the project requirements. General definitions for a positive (+) impact to each of the categories are outlined.

Cost

A positive (+) impact reduces capital costs by least 10% from industry standard of current practice.

Quality

A positive (+) impact reduces defects, failures, leaks and/or improving tolerances, aesthetics, durability, comfort, and, functionality.

Schedule

A positive (+) impact shortens activity duration by at least 10% from industry standard of current practice.

Process Efficiency

A positive (+) impact eliminates or significantly reduces unnecessary design or management work in the delivery process.

Safety/Health

A positive (+) impact to safety/health improves safety of construction/facility workers and/or health of building occupants, including indoor air quality.

Maintainability

A positive (+) impact to maintainability improves startup costs, maintenance time/productivity, accessibility, reduce training, or ease of retrofit for future renovations when compared to the industry standard or existing practice.

Resource Use

A positive impact to resource use reduces the quantity of resources (energy, water, land, materials) consumed, used, or wasted when compared to industry standard or current practice.

Leadership in Energy and Environmental Design Credit

This identifies the impact a PVE suggestion has on a certain credit in the U.S. Green Building Council's LEED rating system. A positive (+) impact to LEED credit contributes to the project achieving a particular credit.

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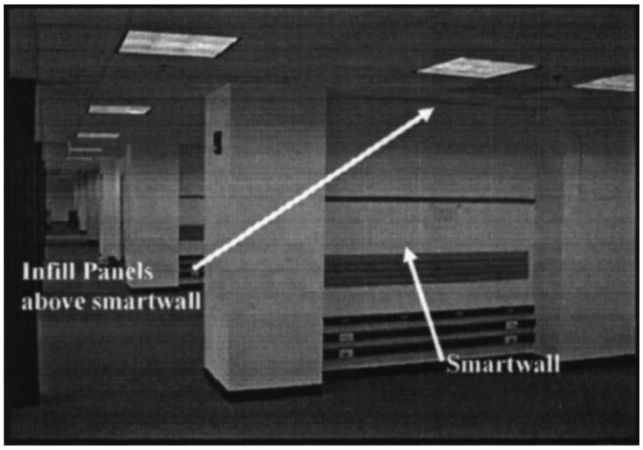

Fig. 3. Smartwall system used at Pentagon with infill panels above

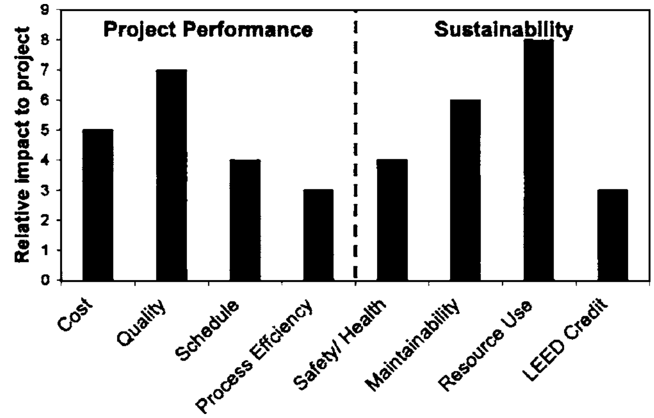

Fig. 4. Sample balanced continuous value enhancement process metric

Example Potential Value Enhancement

An example PVE identified at the Pentagon renovation demonstrates the CVEP process. This example is the off-site prefabrication of the "smartwall" system (Fig. 3). Smartwalls are, 1,800 mm (6 ft) high walls placed between columns which hold the complete electrical wiring, telecommunications cables, and connection systems needed at each desk unit. This prefabricated wall system was selected over the alternative (2×4 wood framing with drywall) to enhance the flexibility of the space. The ability to move this system assists in facilitating the rapid reconfiguration of space, while creating minimal disruption and nearly zero waste. The manufacturer estimates that this feature will save approximately 2 million kg (4.5 million lb.) of debris (drywall and stud frame off-cuts, jointing compound, paint, and rewiring) over the 50 year life of the building. An analysis of the smartwall system using the CVEP rating system is provided in Table 1. Applying the weighted factors from Fig. 2 results in a total weighted score of 0.250, indicating this PVE is aligned with the owner's values and should be implemented (note: the values in Fig. 2 are used for illustrative purposes only and do not reflect the priorities of PENREN).

Table 1. Continuous Value Enhancement Process Rating for Smartwall System Used on Renovation of Wedges 2–5 of Pentagon.

Rating	Weight	Description
(−)	0.107	**First cost**: The increased cost to manufacture the system was offset by the reduction to the construction schedule.
+	0.107	**Quality**: Significantly increased quality of the system. Less variation.
+	0.107	**Schedule**: Shortened construction schedule.
(−)	0.250	**Process efficiency**: Reduces process efficiency due to increased design work.
+	0.143	**Safety/health**: Improves safety due to less onsite activity.
+	0.214	**Maintainability**: Improves maintenance and eases future retrofits or renovations due to enhanced accessibility.
+	0.036	**Resource use**: Reduced waste due to production in manufactured setting.
0	0.036	**LEED credit**: Does not affect any specific LEED credit.
	0.250	**Total weighted score**

Note: LEED=Leadership in energy and environmental design.

Continuous Value Enhancement Process Project Metric

The CVEP metric provides crucial information on the focus and quality of the effort exhibited by the project team in balancing project performance issues with sustainable building objectives. Two sample CVEP metrics are provided in Figs. 4 and 5. Ideally, teams should be striving to find solutions that achieve a balanced effort across all categories, while focusing on those areas of highest priority to the owner. Fig. 4 clearly shows a balanced effort on both sides of the metric, but Fig. 5 shows an unbalanced effort suggesting that the project team is placing greater emphasis on project performance and than sustainability. In this capacity, the CVEP metric provides a mechanism to clearly summarize this information to senior management. This in-process metric provides additional insight into project team dynamics and identifies some of the factors driving the decision making process.

The CVEP metric is calculated by summing the relative impacts (+1, 0, or −1) of the PVEs in each rating system category. The totals for each rating system category are calculated and then

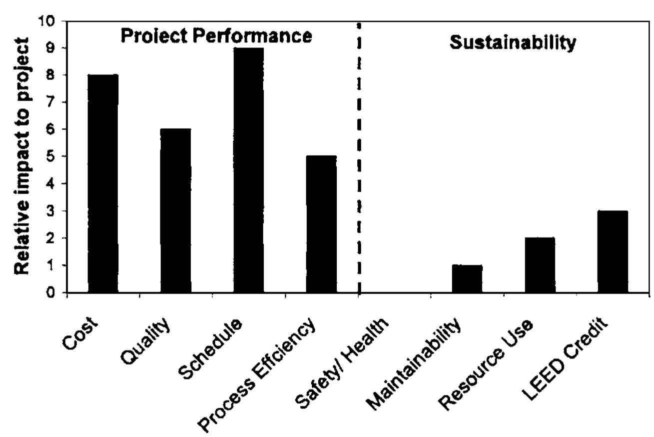

Fig. 5. Sample unbalanced continuous value enhancement process metric

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plotted on the CVEP metric axis. For example, five out of ten PVEs for Fig. 4 had a positive impact to project cost and thus the CVEP Metric indicates a value of +5.

Information concerning the potential and actual cost savings to the project can also reported as well as the best PVE of the month to provide individual recognition and rewards to helps motivate personnel to identify innovative solutions. After collecting PVEs for several months, cumulative values can also be plotted to illustrate trends concerning the focus of ideas generated by the project team.

Model Testing

The CVEP was tested on two case study projects at the Pentagon to determine if the tool was able to systematically identify project solutions that improve project performance *and* increase levels of sustainability.

The first case study project (Project 1) is the Wedges 2–5 Pentagon renovation project. This is a phased design-build renovation of 420,000 m^2 (4.5 million ft^2) of office and support space in the Pentagon. The scope of work includes removal of all hazardous materials, replacement of all building systems, the addition of new elevators and escalators to improve vertical circulation, and installation of new security and telecommunications systems. The project, underway since September 2001, is on an accelerated schedule due to a Congressional mandate. The project is a complex office renovation and is on target for Silver certification under the U.S. Green Building Council's LEED rating system.

The second case study project (Project 2) is the Pentagon Heating and Refrigeration Plant (H&RP) Intake/Outfall project whose scope was to install a new condenser cooling water system. The 2.4 m (8 ft) diameter intake line will convey water from a local lagoon to the H&RP. The 1.5 m (5 ft) outfall line dispenses the warmed condenser cooling water to a waterfowl sanctuary. The scope of work involves the construction of an intake structure, $12.2 \times 12.8 \times 6.7$ m deep ($40 \times 42 \times 22$ ft deep). Two concrete vertical shafts, 9.8 m (32 ft) diameter $\times 21.3$ m (70 ft) deep, connect the intake line from the intake structure to the screen house. Originally these shafts had different diameters which required two separate sets of customized formwork. The intake line is approximately 183 m (600 ft) and the outfall line is 366 m (1,200 ft). The team for this project differed to the team for the Wedge 2 project, and this project did not pursue LEED certification.

Data Collection

The PVEs on both projects were collected through semistructured interviews with the project team leader, design manager, and a construction/field manager from each project. The PVEs and associated impact ratings to performance categories were captured in a spreadsheet. These participants were selected as they possessed the greatest understanding of the impact decisions have on the performance of their project. Interviewees were asked to provide PVEs for their project and rate the impact each PVE had on the performance categories. Unstructured interviews with additional project team members, and on-site visual inspections were performed to filter the data collected for accuracy in the descriptions, cost estimates, and performance ratings collected.

Data Analysis

To assess the ability of CVEP to identify project solutions that improve project performance and increase levels of sustainability, two analyses were performed. In the first, the summation of PVE ratings for constructability (project performance) (ΣPVE_c) was compared to the summation of PVE ratings for sustainability (ΣPVE_s). As shown in the following equation, if the difference between the values in each group is less than 33%, then CVEP is collecting PVEs that affect both project and sustainable performance:

$$\frac{\Sigma\text{PVE}_c - \Sigma\text{PVE}_s}{\Sigma\text{PVE}_{\text{total}}} < 33\% \qquad (1)$$

In the second analysis, 75% of the PVEs identified had to have positive impacts in both constructability ($\Sigma\text{PVE}_c > 0$) and sustainability ($\Sigma\text{PVE}_s > 0$). The ratings for each PVE in constructability (project performance) are summed (ΣPVE_c). Then the ratings for each PVE in sustainability are summed (ΣPVE_s). All PVEs with positive impacts in both areas are compared to the total number of PVEs identified. This comparison evaluates whether ideas of significance are being obtained by CVEP.

Results

Project 1

Thirteen PVEs were collected from Project 1 and these are presented in Table 2, with the corresponding CVEP Metric in Fig. 6. The total relative impact of PVEs in constructability-related rating categories was 24. The total relative impact of PVEs in sustainability-related rating categories was 33. Eleven PVEs had positive impacts on both sustainability and constructability.

In the first test, the difference between the impact to sustainability (33) and constructability (24) was nine. This equates to a difference of 27.2% (9 divided by 33). As this is less than the baseline 33%, the first test is satisfied. Eleven out of 13, or 84.6% of the PVEs identified had positive impacts to both sustainability and constructability. As this is greater than the baseline 75%, the second test is also satisfied.

Project 2

A total of seven PVEs were collected from the Intake/Outfall project and these are presented in Table 3 with the corresponding CVEP Metric in Fig. 7. The total relative impact of PVEs in the constructability-related rating categories was 16. The total relative impact of PVEs in sustainability-related rating categories was 12. All seven (100%) of the PVEs had positive impacts to both constructability and sustainability.

In the first test, the difference between the relative impact to sustainability (12) and constructability (16) was four. This equates to a difference of 25% (4 divided by 16). As this is less than the baseline 33%, the first test is satisfied. All of the value enhancements identified had positive impacts to both sustainability and constructability which satisfies the second test.

Examples of PVEs identified in the first project include using carpet tile instead of broadloom carpet, factory applied carpet on access flooring, and the use of mechanically crimped pipe fittings (e.g., ProPress). One key value enhancement on the second project changed the diameters of the large concrete shafts to match each other which allowed the custom formwork to be reused. This produced a significant first cost savings. Another PVE was the resequencing of construction activities to reduce con-

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Table 2. Potential Value Enhancements Collected from Project 1

Potential value enhancements	Cost	Quality	Schedule	Process efficiency	Safety/health	Maintainability	Resource use	LEED credit
Offsite fabrication of the smartwalls	0	1	1	−1	1	1	1	1
Carpet tile in lieu of broadloom	1	1	1	1	1	1	1	1
Mechanically crimped (propress) fittings versus solder joints in the plumbing piping.	1	1	1	1	1	1	0	0
The universal space plan (mockup) helps to create user acceptance and promotes knowledge of the new systems and functionality of the space.	1	1	1	1	1	1	1	0
Use of PDS ribbon fiber significantly reduces the amount of EMT required.	1	0	1	0	0	1	1	0
Kit of parts furniture as a standardized, repeatable component of the building system.	1	1	1	1	0	1	0	0
Optional glass infill panels maximize day lighting within delineated suites.	0	1	0	0	1	1	0	1
Factory applied carpet on access flooring improves air quality onsite (glue vapors) and reduces the risk of safety hazards.	0	1	1	0	1	1	0	0
Energy management control system to control lighting and heating, ventilation, and air-conditioning.	0	1	0	0	1	1	1	1
Recycled content gypsum wallbroad	0	0	0	0	0	0	1	1
Low-e windows throughout the building	0	0	0	0	0	0	1	1
Refurbish existing handrails	1	0	−1	0	0	0	1	1
Thermostat occupancy pushbuttons recommended versus suite entry pushbuttons for after hours override lighting control	1	0	1	−1	0	1	1	0
Totals	7	8	7	2	7	10	9	7

Note: LEED=Leadership in energy and environmental design.

struction joints. These examples represented significant project decisions and captured many of the innovative ideas implemented on each project.

Discussion

The results verify the functionality of CVEP to systematically identify project solutions that improve project performance *and* increase levels of sustainability. This project management tool is specifically designed to meet the rigors and challenges associated with sustainable projects. Not only does CVEP provide a mechanism to identify high performance building solutions, it also provides a means to measure and monitor the decision-making process through the CVEP metric.

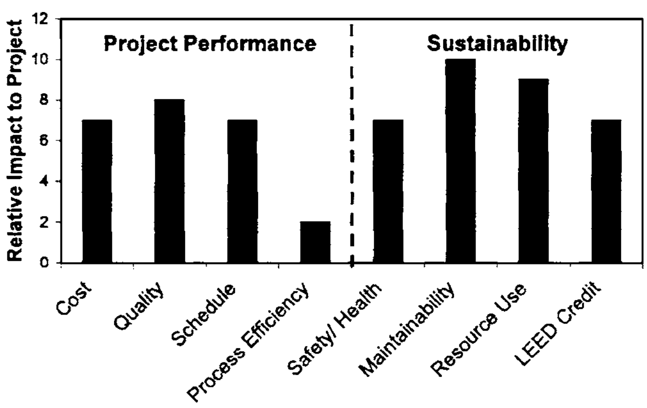

Fig. 6. Continuous value enhancement process metric for project 1 (wedge 2)

Both project teams had few difficulties rating the examples in accordance with the categories and assessment rules of CVEP. The CVEP metric from Project 1 is illustrated in Fig. 6 and reveals a balanced effort existed across both areas of performance. One noteworthy observation from this metric is the result for process efficiency which appears to be relatively low compared to the other categories. There could be two explanations for the lower result: Either the examples had very little effect on the design or management effort, or some examples has positive impacts to process efficiency while others had negative impacts, thus balancing out. A review of the PVEs collected found the latter to be true. The data shows that three PVEs resulted in positive impacts to process efficiency, while two had negative impacts. This result also highlights the importance of a positive process efficiency category to project managers. A positive result in this category indicates that, on average, more of the PVEs improve the efficiency of design and management. This metric provides additional insight to project managers on the focus and quality of PVEs generated by the project team.

The CVEP Project metric for Project 2 (Fig. 7) illustrates a relatively well balanced effort between cost, quality, schedule, and safety/health and resource use on this project. Very few LEED credits could ever be obtained on this project, due to its nature, thus explaining the low value in this rating category. A process efficiency total value of −1 indicates that overall, the examples provided will likely require more work by the project team to implement. After reviewing the examples, it was clear that the reason for these additions was because the issues were not addressed at the proper time during design. One example which had a negative impact to process efficiency was the change from bolted to welded connections which occurred just before construction began, resulting in significant design rework. In sum-

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Table 3. Potential Value Enhancements Collected from Project 2

Potential value enhancements	Cost	Quality	Schedule	Process efficiency	Safety/health	Maintainability	Resource use	LEED credit
Make interior diameters of major concrete shafts equal to allow for formwork reuse.	1	0	1	0	0	0	1	0
Resequencing construction activities to reduce unnecessary construction joints (nine joints were eliminated in the walls and three in the slab).	1	0	1	0	1	0	1	0
A reinforced concrete cylinder pipe (RCCP) was used over the reinforced concrete pipe. The RCCP was a higher grade of pipe with an internally cast liner, which eliminated a steel casing typically required. One pipe installation process in lieu of two. No internal stressing required (reduces possible failure rate during jack and bore installation).	1	1	1	0	0	0	1	0
Raising the elevation of the pipe so that it was above the tidal water line eliminated the need for a flap gate.	1	0	1	1	1	1	1	0
Low head hydroturbines are suggested to recover energy spent from pumping the outfall discharge water over the antisiphon loop, 40 ft of head pressure can be recovered and used to produce electricity.	0	1	1	−1	0	0	1	1
Detailed load calculations revealed the diameter of the pipe for the intake and outfall could be reduced to a smaller size.	1	1	1	0	0	0	1	0
Steel connections changed from bolted, to joint penetration, and then to Phillips welds (more typical detail). Bearing plates and stiffeners were eliminated. Reduced manpower and material usage.	1	1	1	−1	1	0	1	0
Totals	6	4	7	−1	3	1	7	1

Note: LEED=Leadership in energy and environmental design.

mary, the CVEP metric can provide valuable insight into the quality and focus of decisions made by project teams.

Conclusions and Further Research

Sustainable building objectives often impose arduous requirements on the project team, and hence are not always addressed in the most effective or efficient manner possible. The CVEP was developed as a project management tool to integrate sustainability into project management through constructability and value engineering practices. The metric created provides project managers with previously unavailable information concerning the focus of ideas generated or decisions made by the project team. This metric illustrates which areas of performance project teams are concentrating their efforts on. This is significant as it provides a means to gauge whether the teams' decisions or ideas being generated are aligned with values of the customer (building owner). More importantly, this information is provided in real time, so corrective measures can be taken, if necessary, to more closely align project decisions with customer values.

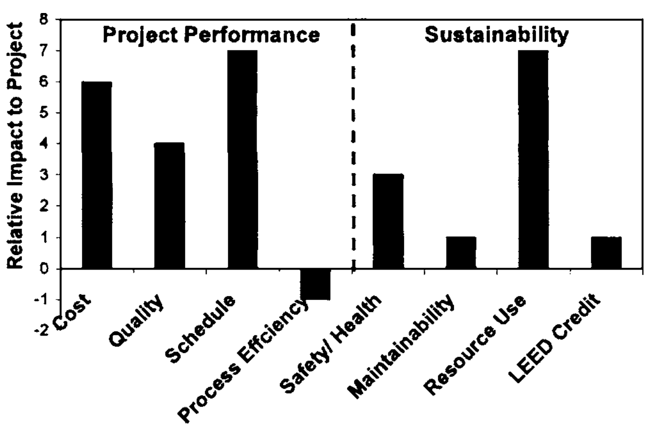

Fig. 7. Continuous value enhancement process metric for project 2 (intake/outfall)

This project management tool combines the best practices from several fields including constructability, value engineering, and lean production to improve the management of projects with sustainable objectives. The tool can be used by industry members to integrate sustainability into current project management systems. The generic process model and metric should be transferable between construction markets and sectors. The only element that would change might be the specific rating system categories depending upon unique project requirements. The CVEP provides industry practitioners with a method to harness the knowledge and competencies of owners and construction professionals to generate high performance building solutions that are aligned with the owner's priorities. The CVEP was tested on two case study projects at the Pentagon and the results verified the functionality of the model. The CVEP has the opportunity to improve the delivery of sustainable building projects.

As sustainable project development continues to mature, new ways for achieving sustainability without adding to project cost or the workload of the team are needed. The next step in the development of CVEP is to validate the model by analyzing its ability to impact project performance levels. Other research is also needed. The vision for CVEP is to integrate sustainability into project management on construction projects as seamlessly as possible. Research is needed in all fields of specialized expertise

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in the construction industry to examine the value that can be contributed to enhancing sustainability, as this is a critically important emerging field that has broad reaching impacts on society.

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