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SUSTAINABLE IMPLEMENTATION OF SPIM IN A CONSTRUCTED WETLAND PROJECT

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Abstract. *Constructed wetlands are capable of purifying water quality effectively; however, they are currently managed using conventional management models, which are incapable of responding to various changes that occur during the construction process, thus resulting in numerous failures. This study proposed a sustainability performance indicator model (SPIM) to implement the sustainable performance control of projects, and the results are examined through the case study of a constructed wetland. The results indicated that projects using the SPIM have higher integrity and implementation effectiveness, verifying that the SPIM is capable of facilitating the sustainable performance of constructed wetland projects.*

Keywords: Sustainability, Performance indicators, Constructed wetlands, Ecological engineering, Life cycle

1. Introduction.

1.1. **Background.** Taiwan is one of numerous countries with limited water resources [1]. Its rivers and reservoirs are often polluted and this causes eutrophication, with severe cases of pollution leading to toxic substances in the water [2,3]. The purification of water is thus an urgent challenge for the country. The Taiwanese government has previously devoted considerable resources to the development of numerous constructed wetlands using ecological engineering in various locations [4]. The results of this construction verified that improving water quality is possible, with approaches such as the elimination of nutrients and suspended solids yielding satisfactory results [5]. Statistical data have indicated many failures in constructed wetlands [6,7], which result in the poor performance of public constructions and significant financial losses for the government. The inspection and acceptance stages of constructed wetland projects determine the success of the overall project and are the key periods during which remedial measures can be taken although the relevant authorities are generally not concerned about these stages. Problems during these stages include corner cutting reducing construction costs at the expense of the ecology, and continuing construction without notifying the design units if the environmental conditions are discovered to differ from the original design conditions. Constructed wetland project management currently still follows the traditional construction model, and factors such as the government's recent efforts to decrease the manpower used and give projects to the lowest bidder result in the ineffective and unsustainable implementation of public projects. Taking sustainable development as its goal, this study

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introduced construction management and performance-based contracts into the construction process [8,9]. Constructed wetland projects involving complicated and difficult to control ecological environments were selected, and the effectiveness of the sustainability of the inspection and acceptance stages was investigated using the proposed sustainability performance indicator model (SPIM) management practice. The academic contributions and results of this study include: (1) Propose a schematic for sustainable development of a project; (2) Propose SPIM to assure the sustainable development of a project; and (3) Use a case study to demonstrate the application of SPIM on constructed wetland and verify the feasibility which can be future reference.

1.2. **Literature review.** Wetlands are the most productive ecosystem on the planet, having productivity 2.5-4 times that of general fertile land [10]. They have various crucial functions that contribute greatly to the sustainability of the Earth; water purification, torrent prevention, prevention of saltwater intrusion, and the breeding of natural resources for example [11]. Constructing wetlands using ecological engineering technology is capable of removing particulates and dissolved contaminants from water. Campbell stated that sustainable development is the realization of social welfare through economic development based on natural resources [12]. The concept of sustainable development proposed by Munasinghe included economic, social, and environmental dimensions, which have competing and coordinated relationships with each other [13]. Scholars worldwide have developed numerous sustainability indicators to promote sustainable development policies [14-16]. Engineering project management has gradually shifted from a traditional model to sustainable development models in recent years. Performance-based contracts (PBCs) use the outcome or performance of the project goals rather than the traditional input, technology, or implementation process – as the basis for project inspection and acceptance [17,18].

The literature reviews of constructed wetlands are mostly on construction technology [19]. There is very little research on the innovative approach of construction management for the constructed wetlands. The traditional management model is currently applied for the constructed wetland project [20]. The traditional management model is based on the construction target as management kernel. In order to pursue profits, the project constructors focus on reducing costs [21]. This will lead to endless problems for the project [22]. The traditional management for the constructed wetlands is simply achieving the completion of the project. It is lack of comprehensive consideration of effects for the whole life cycle of the project [21]. The constructors are more concerned about being in compliance with the rules than the effectiveness of performance; thus the designer and the constructor do not cooperate well [23]. Due to the fact that the environmental conditions of the constructed wetlands are complex, the traditional management model is unable to cope with the climate change and high environmental awareness of publics. The innovation of the management approach proposed in this study is to set a comprehensive target for the project. The construction process with the comprehensive target can effectively implement the sustainable development for the constructed wetlands.

The remainder of this paper is organized as follows: Section 2 includes the research design of this study, the definition of the sustainability performance targets, and further introduction of the SPIM for the constructed wetland; Section 3 outlines the introduction of used case, discusses the study results of the SPIM case, and aggregates the implementation benefits of the SPIM; finally, Section 4 concludes and makes suggestions.

2. SPIM for Constructed Wetland.

2.1. **Research design.** This study examined the sustainable goal structure of wetland projects through actual cases and relevant literature in order to establish the factors crucial for achieving sustainable development. An embryonic form of the SPIM was then constructed. To verify the validity of the model, 35 experts with relevant experience in sustainable projects or constructed wetlands were interviewed. Statistical analysis revealed that the experts' opinions on the indicator test content of the model were as follows: (1) the sustainability performance indicator items of prominence accounted for 36.56% of the 93 items; a total of 34 indicators were thus retained; (2) the acceptance of the requirement standard was more than 80%; (3) the acceptance of measurement method was more than 80%; and (4) the acceptance of the tolerance interval or reaction time was more than 69%. The model was modified according to the analysis results and suggestions.

2.2. **Sustainability performance targets.** Constructed wetlands are dynamically balanced natural environments. The climate, geography, and ecology in different regions of various countries are distinct. Therefore, performance goals must be developed based on different conditions and are subject to adjustment according to environmental changes. This study explored water resource development policies to construct sustainability target framework and establish distinct sustainability performance goals under the overall sustainable goal of constructed wetlands. Based on the sustainability performance target conditions in their contracts, the main objectives of contractors must include sustainability performance targets into their projects, including targets such as project proposal, operation regulations, and voluntary inspection.

2.3. **SPIM of constructed wetlands.** The SPIM of constructed wetlands is based on the Sustainable Performance-Based Contract under which the inspection standards of SPI are applied on sub-construction planning, sub-item material planning, sub-item equipment planning, detailed development planning and other sub-item planning (Figure 1). The SPIM of constructed wetlands consists of 34 indicators that possess clarity, scalability, clear measurement procedures, threshold values, and relative reaction time (Table 1). The SPIM is guided by the sustainable objectives of projects, using the innovative models of PBCs as an incentive for constructors to follow the detection and control management process. Whether a project is sustainable is determined using the judgment criteria. In the

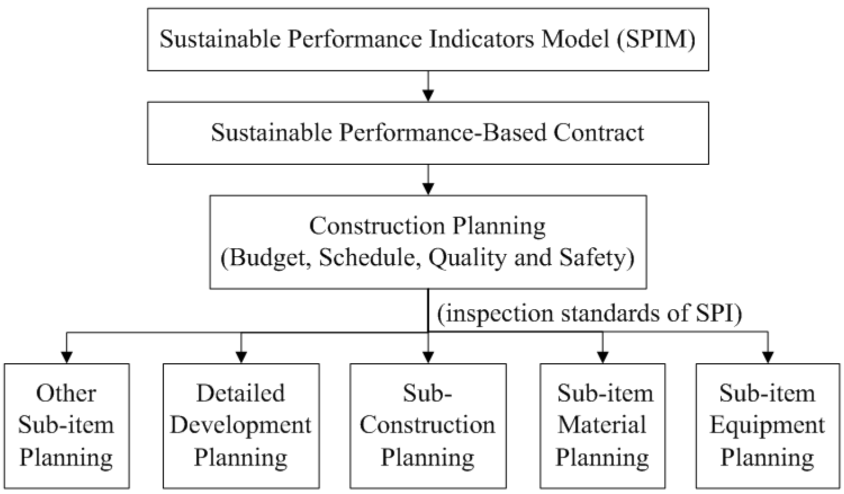

FIGURE 1. Hierarchy of SPIM

TABLE 1. Test results for sustainability performance indicators

Index Number	SPI	Requirement Standards	Reasons for Nonconformation to the Standards	Data Source	Indicators Used	Inspection Results	Eligibility
SP01	Base subsidence area	Each subsidence area $\leq$ 0.7 m^2; total subsidence area $\leq$ 2 m^2	Subsidence areas = 8 m^2 and 3.5 m^2; total subsidence area > 11.5 m^2	On-site measurement	●	2 locations in total	NO
SP02	Pool/riverbank slope collapse	Collapsed area at each location $\leq$ 0.3 m^2; total collapsed area $\leq$ 1 m^2	Total collapsed area = 6.4 m^2	On-site measurement	●	4 locations in total	NO
SP03	Potholes	Base pothole diameter < 8 cm; pothole depth < 0.8 cm	Base pothole diameter = 28 cm; pothole depth = 12 cm	On-site measurement	●	1 location in total	NO
SP04	Amount of locally obtained material	Amount of locally obtained material > 20% of total materials purchased	Amount of locally obtained material = 9% of total materials purchased	Recorded data	●	< 20%	NO
SP05	Pool water level	Mud clearing required if average depth < 30 cm	Project not completed	–	○	–	–
SP06	Water leakage from the pool	Water leakage < 5%	Water leakage = 8%	On-site measurement	●	> 5%	NO
SP07	Inflow and outflow rate in the pool	Pool water inflow/outflow	Project not completed	–	○	–	–
SP08	Pool water pollution	Odor, temperature, turbidity, pH, electrical conductivity, BOD_5, total suspension solids, CI-, should be in line with the design value	Construction in progress; pool not yet operational	–	○	–	–
SP09	Cost of energy consumption during the construction project	Cost of nonsustainable energy used by construction equipment < 70% of total cost of fuel consumed during construction	Project not completed	–	○	–	–
SP10	Base cleanliness	Base area should be kept clean of soil, debris, and garbage	Base was littered with plastic bottles, and the ecological pool was filled with abandoned steel	On-site measurement	●	5 locations in total	NO
SP11	Amount of toxic substances in materials	Toxicity measurement $\leq$ regulation standards	Toxicity measurement of impermeable clay < regulation standards	Recorded data	●	$\leq$ regulation standards	YES
SP12	Cost ratio of using products with green material labels	Cost of products with green material labels > 70% of total material costs	Project not completed	–	○	–	–
SP13	CO_2 emissions during construction	CO_2 emissions calculated from energy and resources used < 60% of total CO_2 emissions from construction	Project not completed	–	○	–	–
SP14	Interference area the of construction around the base	Interference area $\leq$ 0.5% of the work site area	Interference area up to 20% of the work site area	On-site measurement	●	> 0.5%	NO
SP15	Proportion of area that is ecologically engineered	Ecological engineering area $\geq$ 90% of construction area	Ecological engineering area = 25% of construction work area	On-site measurement	●	< 90%	NO
SP16	Survival ratio of wetland plants	Survival area of plant cultivation $\geq$ 90% of plant cultivation area	Average survival of planted area = 17%	On-site measurement	●	< 90%	NO

(continued)

Index Number	SPI	Requirement Standards	Reasons for Nonconformation to the Standards	Data Source	Indicators Used	Inspection Results	Eligibility
SP17	Proportion of ecological professionals involved in project	Ecological professionals $\geq$ 80% of total engineering staff	Ecological professionals = 15% of total engineering staff	Recorded data	●	< 80%	NO
SP18	Proportion of biomass changes	Reduction in number of biological groups during construction $\leq$ 80% of total number of biological groups before construction	Reduction in number of biological groups during construction = 88% of total number of biological groups before construction	Recorded data	●	> 80%	NO
SP19	Number of air pollution cases reported	Average cases per month $\leq$ 1	Average monthly cases = 2	Recorded data	●	> 1 case	NO
SP20	Number of noise complaints filed	Average cases of noise interference per month $\leq$ 2	Average monthly cases = 1	On-site measurement	●	$\leq$ 2 cases	YES
SP21	Number of public complaints filed	Average cases per month $\leq$ 3	Average monthly cases = 2	Recorded data	●	$\leq$ 3 cases	YES
SP22	Cost ratio of river and riverbank disaster damages	Cost of river and riverbank disaster damages $\leq$ 3% of total project cost	Cost of river and riverbank disaster damages = 7% of total project cost	On-site measurement	●	> 3%	NO
SP23	Cost ratio of work area safety and disaster prevention facilities	Cost of work area safety and disaster prevention facilities $\geq$ 1.5% of total project cost	Cost of actual safety and disaster prevention facilities and measures = 1.4% of total construction cost	On-site measurement	●	< 1.5%	NO
SP24	Cost ratio of historical monument preservation	Preconstruction survey required when the cost of historical monument preservation $\geq$ 1.5 $\times$ the monument value	No such item in the construction area	–	○	–	–
SP25	Ratio of disadvantaged laborers hired	Proportion of laborers hired who were disadvantaged $\geq$ 30%	Proportion of labors hired who were disadvantaged = 10%	Recorded data	●	< 30%	NO
SP26	Number of people managing the relevant public hearings and briefings	Number of people managing the relevant public hearings and briefings per month $\geq$ 125 people, 5 times per month	Number of people managing the relevant public hearings and briefings per month = 53 people, 2 times per month	Recorded data	●	< 125 people, 5 times per month	NO
SP27	Construction quality of facilities	No loose peelings on the facings, pavements, or facilities	Cracks and peelings on the material comprising the walkway railing; flakes and beehives on the concrete of the water intake well	On-site measurement	●	2 locations in total	NO
SP28	Protrusion or depression of pavements	Depth or height of protrusion or depression < 1.5 cm; diameter < 15 cm	Height of protrusions on wooden floor of viewing platform = 2.1 cm; depression of environmental protection brick trail surface = 1.8 cm	On-site measurement	●	8 locations > 1.5 cm	NO
SP29	Construction inspection result	Percentage of times a score of A or higher was obtained during inspection (annual average for the past 5 years) $\geq$ 40%	Project not completed	–	○	–	–

(continued)

Index Number	SPI	Requirement Standards	Reasons for Nonconformation to the Standards	Data Source	Indicators Used	Inspection Results	Eligibility
SP30	Proportion of employees who are local residents	Number of local laborers employed/number of foreign workers employed at work site (monthly average) $\geq$ 95%	Number of local laborers employed/number of foreign workers employed (monthly average) = 5%	On-site measurement	●	< 95%	NO
SP31	Proportion of materials and operations sourced locally	Amount of local operations and materials sourced/amount of operations and materials outsourced $\geq$ 6 (85% of total purchase amount)	Amount of local operations and materials sourced/amount of nonlocal operations and materials contracted = 55%	Recorded data	●	< 85%	NO
SP32	Financial balance of project	Income/expenditure $\geq$ 1	Construction in progress, no income data available	–	○	–	–
SP33	Economic benefit of project	Total construction costs for treatment system/Construction costs for general conventional sewage treatment facility < 18%	Construction in progress; total construction costs not yet known	–	○	–	–
SP34	Punctual completion of project	Actual construction duration/planned construction duration $\leq$ 1	Construction not completed	–	○	–	–

case of control mechanisms, project operations are performed following the construction process and a monthly inspection and acceptance result is produced to enable service assessment.

The SPIM proposed by this study can assess the sustainability of the project at any time. The SPIM has 34 SPIs, which have the characteristics such as clear, measurable, well documented, with thresholds, and relative time effect. Each SPI defines the standard to illustrate the maximum allowable range of the indicator. When the values exceeded the standard, the appropriate improved actions must be made within the specified time to prevent the project from becoming unduly deteriorated. The quantitative data obtained through the sustainability test on the project can be the determination basis between the owners and the contractors. The constructor can develop the construction plan based on the overall sustainable operation of the innovative program. The SPIM emphasizes the sustainability of the project through the sustainable innovation to achieve the balance among environmental, economic and social dimensions. The SPIM is a model that performs continuous correction through the feedback from each project to achieve its stability and soundness.

3. Case Study.

3.1. **Case introduction.** The case study in this study was a constructed wasteland project in Northern Taiwan that was located in the high riverbank area beside a main river on the periphery of a city. The free water surface system was adopted for this case study; a waterway was installed at the top of the area to channel water from the river, which was then subjected to initial treatment in a sedimentation tank. The water next flowed into a wetland purification system comprising a first dense planting area, open water, and second dense planting area. Subsequently, the water was discharged into the river. The construction period was December 2013 to February 2015, and the project included earth excavation and backfilling, impermeable clay filling, compaction, transportation, riverbank slope protection grouting, paving, planting, plumbing and electrical work, and other ancillary operations.

3.2. **SPIM case study results.** There are 23 indicators performed for the sample project between September and October 2014 (marked with "●" in the "Indicators Used" column in Table 1). The obtained inspection results and eligibility of these indicators were also listed in the table. The results indicated that numerous aspects in this case study did not meet the required sustainability standards. In Table 1, the SP02 indicated that many collapses which were caused by the insufficient compaction density of the construction process, the insufficient carrying capacity of the gradation, and high proportion of the clay content. These factors have caused the pool with weak structure and lacking of impervious function. The pool might collapse and leak during the raining days. The water shortage of the pool might affect the performance of the water purification system and exacerbate the deterioration of the river pollution. This problem not only directly affected the effectiveness of environmental maintenance, but also indirectly influenced the economic dimension and social dimension of the target. This showed that the traditional management style which could only check the cost target and quality objectives might easily lead to project defects and cannot achieve sustainable benefits. The SP28 reflected the construction quality of the wooden walkways and information platform was extremely poor, with the uneven, overlapping, and broken wood-plastic composites visually unappealing and causing visitor injuries, which resulted in an increase in visitor complaints and negatively affected the social dimension. The traditional management model completely ignored the feelings of social groups and the lacking of multi-dimensional consideration. Compared to the traditional goal, the SPIM has a comprehensive sustainable goal, and it can effectively implement the sustainability of constructed wetlands. Table 2 and Table 3 are the test results of sustainable performance indicators SP-02 and SP-28. The statistical results presented in Table 1 indicated that a total of 20 indicators were unqualified, with the proportion of noncompliance reaching 87%, far higher than the 40% of the test

Table 2. Test result of sustainable performance indicator SP-02

SPI	Description	Measurement method	Improvement time
Pond/riverbank slope collapsed	Total collapsed area = 6.4 m^2	Measured using tape measure	Repair completed within 3 days

Table 3. Test result of sustainable performance indicator SP-28

SPI	Description	Measurement method	Improvement time
Protrusion or depression of pavement	Protruding height of wooden floor of theviewing platform = 2.1 cm; depression of environmental protection brick trail surface = 1.8 cm	Measured using a short ruler	Should be repaired or dismantled and redone within 7 days

criteria value. Therefore, this case study project was determined to be "nonsustainable". To verify the accuracy of the findings, the conventional targets reported in the public works audit report of September 4, 2014 were used as the basis for cross-comparison with the SPIM test results. This comparison revealed no significant difference between the evaluation methods. This study thus verified that the proposed SPIM can be used to determine whether constructed wetland projects are capable of sustainable development.

3.3. **Implementation benefits of the SPIM.** The results indicated that the SPIM is capable of providing contractors with a new sustainable innovation program that addresses innovative ecological engineering and the procurement of local subcontractors and materials at the work site. The functions of the SPIMsuch as its driving indicator features, indicator monitoring mechanism, innovative model of PBC-derived sustainability, and reward and punishment mechanismare capable of effectively inspiring contractors' sustainability innovation. The assessment and monitoring of the standards of sustainability not only enable active implementation of the sustainable development of projects, but also drastically reduce inspection-related manpower requirements and enhance the performance of public projects.

4. Conclusion and Suggestions.

4.1. **Conclusion.** This study proposed the SPIM and its case application for the sustainable development of constructed wetlands. The case project was located at a high riverbank area beside a main river in Northern Taiwan. This study employed the SPIM to detect and control the sustainability performance of the project. The results indicated that the noncompliance proportion of the sustainability performance in the case study was 61%; thus, the project was nonsustainable. This verified that the SPIM is capable of detecting the sustainability of a project. The research contributions of this study are as follows.

A. A framework was established that clarifies the sustainable goals of a project: a project can develop differing levels of sustainable development targets at all project levels through a systematic procedure; this defines the effectiveness of the project and serves as the basis for assessment.
B. The SPIM was established, which integrates sustainable development and PBC, overcomes the shortcomings of conventional construction management models, and comprises an innovative management model that promotes sustainable development for use in the actual implementation of sustainable development projects.
C. An operation template was proposed for the implementation of sustainable project performance; the SPIM was applied in an actual constructed wetland case study, verifying its feasibility.

4.2. **Suggestions for future research directions.** This study focused on sustainability performance implementation through the inspection and examination of a constructed wetland project. Future research can focus on other types of engineering such as construction, traffic, and road engineering; the SPIM proposed in this study can be employed to establish paradigm practical SPIMs for distinct types of engineering in order to practice sustainable development in all types of construction project.

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