QUALITY MANAGEMENT OF ECOLOGICAL ENGINEERING

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ABSTRACT: Ecological Engineering (EE) refers to all sustainable engineering that can reduce damage to ecosystems and that adopts ecology as a base and safety as an orientation in order to implement conservation of biodiversity and sustainable development. In short, EE attempts to safeguard the ecological environment while any essential construction projects proceed. EE encompasses many fields, including construction skills, ecosystem preservation, landscape, and even related cultures and so on. Such variety results in greater complexity of construction, and, consequently, indirectly increases the difficulty of construction quality control. The objective of our research is to explore a promising model for EE via an extensive literature survey. This model includes three principal stages: plan-design, construction, and maintenance, along with individual accompanying phases concerned with quality control and vital management. In this article, a river restoration example is adopted to describe in detail the critical points of quality control in the three stages (plan-design, construction, and maintenance) of the construction life cycle. This study proposes an integrated structure for quality management of EE to guarantee its quality and to enhance its core applications in order to achieve long-lasting preservation of the environment.

Keywords: Eco-Engineering; Quality Management; River Restoration

1. INTRODUCTION

Natural hazards are phenomena that have the potential to cause disasters and inflict significant damage on many people. In part, traditional engineering concepts or techniques can contribute to natural hazards. For example, a large number of mountainside development projects probably increase the likelihood of mudflows and landslides. Further, a traditional retaining wall is not a suitable technique for sustainable environment. In addition, overuse of concrete can indirectly level down a riverbed, thereby resulting in increased probability of damage to pier foundations of river bridges during the typhoon season. Obviously, human activities can aggravate or even create hazards. Thus it is an admirable goal to employ construction skills in order to reduce the influence of adverse environments. For all of these reasons, Ecological Engineering (EE) has become more and more popular recently.

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2. RELATED WORK

In Taiwan, EE has been adopted in several fields, most notably in river restoration, as with Houfanzikeng Creek, Keelung River, and Takan River, and in hill slope stabilization, such as slope restoration along Route 110. Many related research areas are suitable for EE. The Public Construction Committee (PCC) suggests the seven following prerequisites for successful EE. [1]:

1. Start from proper concepts and mentality.
2. Undertake holistic system planning.
3. Understand current ecological environment.
4. Reduce impact caused by construction to lowest level.
5. Study factors that might cause safety problems and remove those factors from source.
6. Take measures that suit local circumstances and use on-site materials.

7. If it is not necessary, do not do it. Reduce waste of resources.

In related research, Gu [2] described the EE reconstruction situation of Takan River. He emphasized that EE not only improved the water quality, but also provided daily leisure amusement and rest space. Wang [3] proposed a model to evaluate the EE effect of stream habitat. According to Wang's study, the construction period has the greatest impact on underwater organisms. Yeh [4] explored an integrated plan-design model of EE measures for the watershed. The five major stages of this model include objectives of watershed management, watershed characteristics investigation, lineation of planning unit and analysis of engineering methods, allocation and design of structures, and ecological evaluation and extension education. Liu [5] discussed the impact of construction on the river area and also explored the priority of factors that affect the status quo of the river. Related factors include maintaining water quality, avoiding sensitive areas, preserving continuity of vegetation, maintaining basic ecological flow, adopting local materials, creating diversity of habit, establishing ecological corridors, maintaining a good environment for migrant species, and conducting a detailed survey of representative species. Yang [6] proposed five areas and eighteen factors that are metric components of the EE approach. These five areas include environmental analysis, ecosystem design, and natural resource utilization, mitigation of environmental impact, and monitoring and assessment. The most critical factors among those proposed by Yang are ecosystem investigation, habitat analysis of representative species, and utilization of existing nature materials. Chuan [7] presented an assessment model to select an appropriate ecological method for slope protection. This model, establishes three objectives (ecological, environmental, and economical) and twelve criteria to help people choose an optimum method. Chang [8] employed an execution framework to guide the design of road construction projects with EE concepts at each stage of the life cycle. Bergen [9] also proposed some principles for EE design consistent with ecological principles, site-specific context, maintenance of independent functional requirements, energy efficiency information, and acknowledgment of values and purposes that motivate design.

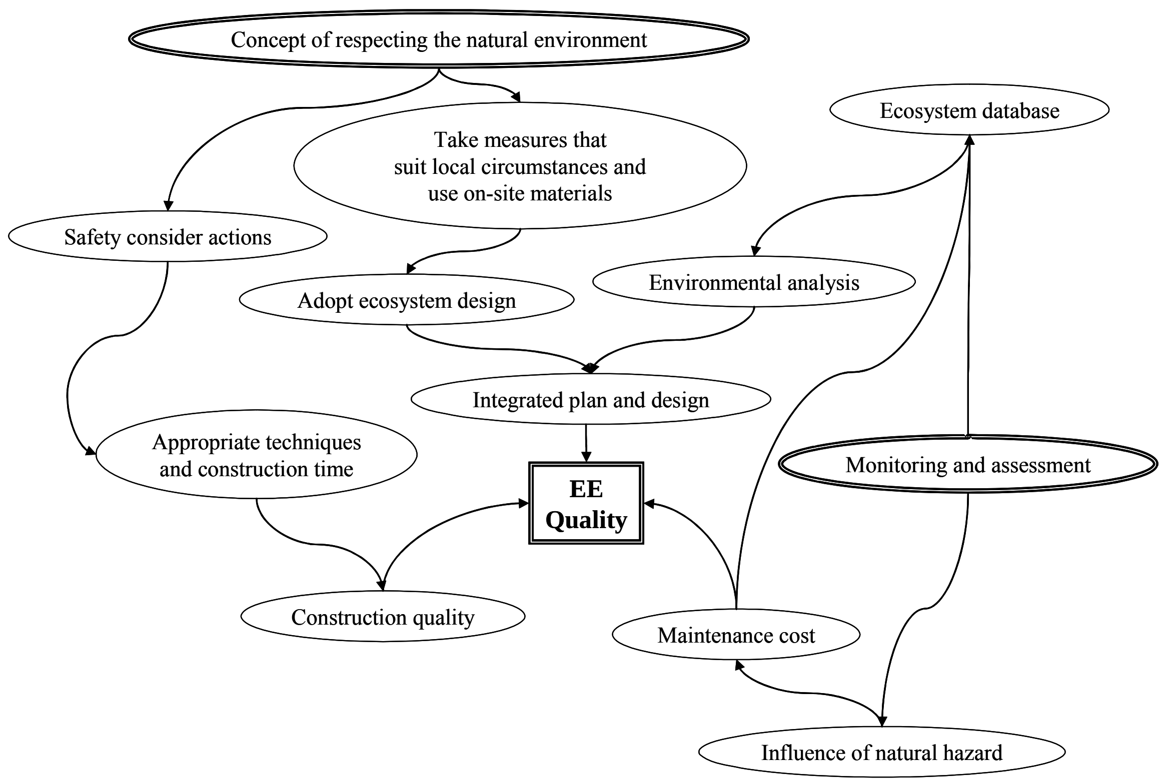

Figure 1. Factors that influence EE quality

Figure 1 (a relations diagram) summarizes factors that influence EE quality. As Fig. 1 shows, in order to achieve improved EE quality at each life cycle stage (plan-design, construction, and maintenance), integrated planning and design, construction quality, and maintenance cost are important factors, but concepts of respecting nature environment and monitor and assessment are the primary goals. The integrated planning and design require detailed environmental analysis to provide the correct related site-status information. The ecosystem database can support the environmental analysis, and the monitoring and assessment system can offer feedback data to the ecosystem database. Thus, monitoring and assessment is a critical point to maintain EE quality. Involvement of people who have the concept of respecting the natural environment is a key factor in adopting ecosystem design, along with the use of appropriate techniques and allotment of suitable construction time. Thus, the concept of respecting the natural environment is a critical reason for improving EE quality.

3. PLANNING AND DESIGN

In order to reduce impact on the environment in the plan-design stage, engineers must choose techniques, equipment, and material appropriate for EE, depending on the condition of the site. Traditionally, examination of the condition includes an investigation of geological prospecting, techniques, resources, traffic, society, economy, culture, and related laws and decrees. EE especially emphasizes exploring the ecosystem and environment, for example, researching biotope types; researching ecological species and their distribution; seeking to avoid destroying activity space of original species and to reduce the impact of civilization on organisms; seeking usable natural resources, such as budding stakes, boulder materials, and vegetation coating material; and seeking to maintain the original natural landscape. Previously employed processes cause traditional construction projects to become more and more complex, and they require support from many different knowledge experts. Moreover, EE attaches great importance to historical information and ecosystem databases. A completed database will save a lot of investigation time.

This section proposes a structure to assist engineers integrate planning and design processes. Figure 2 shows major processes and critical items in the plan-design stage; these processes include five phases. The first phase consists of gathering and analyzing previously compiled information. This phase comprises five important elements, the most important of which is to evaluate the ecosystem via a feasibility study. For thorough control of all information about the construction site, communication with experts or environmental groups is also essential. The second phase encompasses an investigation of site condition background, which involves three events. Building an ecological background database is particularly important because it can save a lot of time investigating the same places in a similar project. The third phase consists of deciding upon design standards and criteria that are dependent on the first two phases. In the fourth phase, visual simulation and forecast techniques can assist in choosing an appropriate method for EE. In the fifth and final phase, construction standards are promulgated.

Moreover, verifying of the planning and design deliverables is very important. Although different projects have different objectives and requirements, ecological environment, site resources, safety, and landscape preservation are the major factors. Table 1 provides a checklist for a river restoration example. It is especially important to ensure that the design selected causes the least impact on the environment.

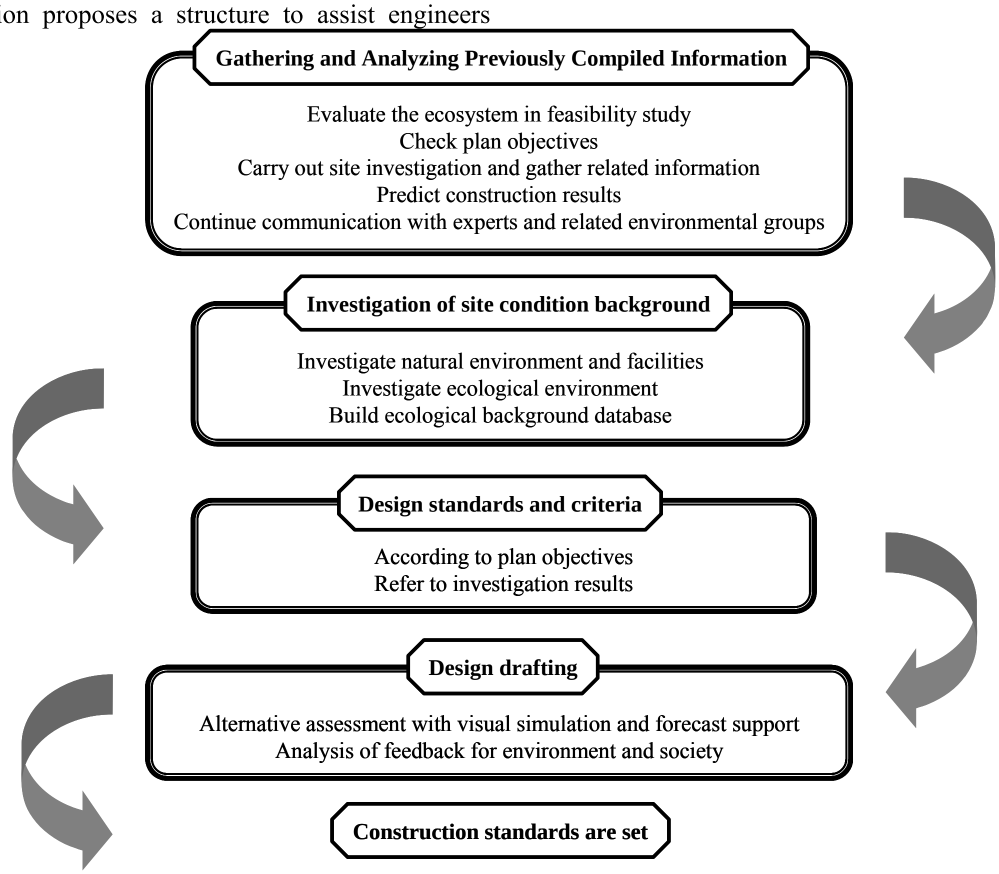

Figure 2. Major processes and critical items in plan-design stage

Table 1. Critical quality items of the plan-design stages in the river restoration example

No.	Critical quality items
1	Is construction or change necessary for the natural environment?
2	Without construction or change, can the objectives of the project still be achieved?
3	Is the design too artificial or complex?
4	Should there be consistency among rest places, ecological environment, and the landscape?
5	Check ownership of construction land.
6	Is design rational for the site condition? (1) Take actions that suit local circumstances, and plan facilities for flood detention. (2) Plan and design to cater to river width and shape. (3) Avoid narrowing river when it wanders.
7	Does the design make economic sense?
8	Construct habitat or ecological corridor to preserve ecological environment.
9	Are materials diversified and in keeping with nature? Can materials be obtained from local sources?
10	Is the structure surface rough and porous?
11	Is the dam graded, with a gentle slope downstream?
12	Is the gradient of retaining embankment a gentle slope?
13	Completed ecological background database.

4. CONSTRUCTION

In order to improve public construction project quality and maintain a quality system, the PCC in Taiwan has been developing a construction quality management system, the Three-Level Quality Management System (TQMS), over a period of more than ten years. According to the definition of the American National Standards Institute [10], a quality system is “the organizational structure, responsibilities, procedures, processes, and resources for implementing quality management.” A quality system includes the entire organization, the quality procedure, and the results of related work. In the construction industry, the system is a complex one because it involves different participants linked by reciprocating relationships, such as the owner, constructor, subcontractors, and supplier. Moreover, a major reason for complications is that specific quality responsibilities of participants are usually poorly defined.

TQMS clearly defines the responsibilities of the owner and contractor. All participants in a project must adhere to the TQMS, unless specified otherwise, when they carry out operations related to public works. TQMS comprises three parts, as described below:

(1) **Quality control (QC, first level):** Quality control is the “specific implementation of the quality assurance program and related activities” [11]. The contractor shall be in charge of quality control (first level). The contents include QC organization, quality management standards, procedures of inspecting construction activity and testing material, a self-checklist, defect correction and preventive measures, internal quality audit and document and record management, safety and environmental, and so on. With EE, construction methods are different from the traditional approach. The contractor must pay special attention to understand the contract and standards and then must establish procedures for inspecting construction activity and implementing self-checklist items. This process can effectively improve construction quality. Figure 3 is a schematic diagram of a procedure for a tree planting and inspection process. Table 2 is a self-checklist example for river embankment construction in a river restoration project.

(2) Quality assurance (QA, second level): Quality assurance is considered to be a “system of controlling the provision of a product or service so as to satisfy the needs of the customer” [12]. With TQMS, project owners perform construction quality assurance (second level). Project owners need to inspect and audit each construction activity according to the contract and supervision plan.

(3) Quality audit (third level): Quality audit is a “formal, independent examination with intent to verify conformance with established requirements, and an audit does not include surveillance of inspection for the purpose of process control or product inspection.” [13]. Government authorities and the PCC are responsible for quality audits (third level).

The PCC used the TQMS and included the unit-in-charge of a project to improve the quality of public construction projects and implement the quality system. At the first level, the contractor should emphasize the importance of a self-checklist. Insofar as possible, the contractor should use quantifiable standards in the checklist. The second and third levels attach importance to inspecting or auditing the quality processes and results. Table 3 displays quality key points for three levels of TQMS in the construction stage of a river restoration project.

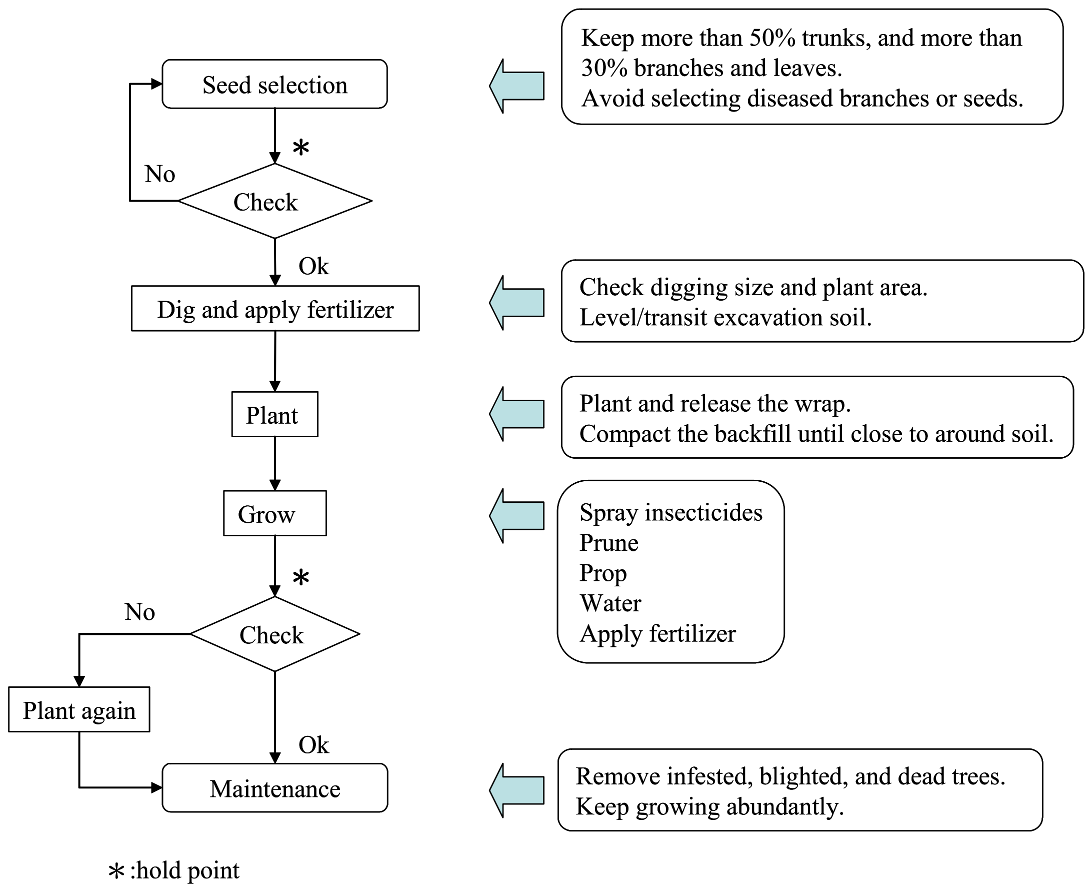

Figure 3. Tree planting and inspection process

5. MAINTENANCE

The maintenance process includes setting up a maintenance organization, establishing an environmental assessment index, and deciding on protected objects, a maintenance policy, and a monitoring and assessment feedback system. This process is illustrated in Fig. 4. Maintenance is a very important ongoing stage for EE. Many successful EE cases around the world are inviting local residents to join in the maintenance work. For example, in Taiwan, the Wild Creek project in Liu Dong, Maioli shares the responsibility of maintenance among local residents. In Germany, the Nidda River project not only encourages local residents to join the maintenance work, but also supports their taking part in river governance. In Japan, an association was made with the local community for regular maintenance of the Habu River project. In this manner, quality of overall engineering can be maintained for a long time.

Moreover, monitoring and assessment of change is also critical during the working stage of each project. A suitable monitoring system that records time series variance after construction is completed can offer feedback data to the ecosystem database. Such a system can provide support to engineers in choosing correct techniques for new EE projects. A fast reaction assessment system can reduce the extension of natural hazards and assist engineers in making decisions regarding maintenance policy. Trout River, located in Vermont in the United States is a successful case study for monitoring and assessment. The river governance plan for Trout River was completed in October of 2000. The major objective of this plan was to reconstruct the previously destroyed area and to avoid future flood disasters. In this case, the effect of torrential rain on the ecology has been monitored over a long period of time[1].

Table 2. Self-checklist for river embankment construction

Construction Name	*** River Restoration		Number	
			Check Date	
			Checker	
Construction Stake Number				
No.	**Item**	**Standard**	**Result**	**Accept**
01	Foundation 175 kg/cm^2PC	H =____cm, W =____cm	H =______cm, W = cm	□yes □no
02	Backfill 175 kg/cm^2PC	T=30cm	T =_______cm	□yes □no
03	Embankment slope	S =_______	S =_________	□yes □no
04	Stone size	Long diameter is 50 ± 10 cm, 70%, bigger stones are on lower level.	Long diameter =_______cm	□yes □no
05	Inlay stone size	Long diameter is 30 to 50 cm, 70%	Long diameter =_______cm	□yes □no
06	Drainpipe	No block	□yes □no	□yes □no
….	…..	….	…..	….
….	…..	….	…..	….

Table 3. Quality key items of three levels of TQMS

First Level (Contractor)	Second Level (Owner)	Third Level (Government Authorities and PCC)
1. Planting 2. Embankment 3. Railing 4. Narrow footway planked over a cliff 5. Pavement - Hollow brick, interlocking concrete pavement, etc. 6. Stone slate seat 7. Groundsill 8. Water-accessible facilities 9. Scenery-seeing flat 10. Pavilion 11. Channel 12. Gabion box 13. Check dam 14. Drainage 15. Drop structure	1. Does quality and construction plan satisfy EE requirements? 2. Does quality organization of contractor perform effectively? 3. Inspection procedures for materials and construction are practicable and carried out at every phase. 4. Verify performance of contractor's self-checklist. 5. Control, correction, and prevention for substandard case. 6. Check source of contractor's material. 7. Project schedule. 8. Influence of environment during construction period.	1. Does inspection plan satisfy the EE requirements? 2. Does inspection organization of owner perform effectively? 3. Processes and results of inspection quality and construction plan. 4. Records of checking materials and facilities. 5. Records of audit for construction quality. 6. Check daily paperwork of supervisors. 7. Tracing state for defaults. 8. Treatment state of unqualified case. 9. Problems regarding construction of contractor. 10. Problems regarding inspection of owner.

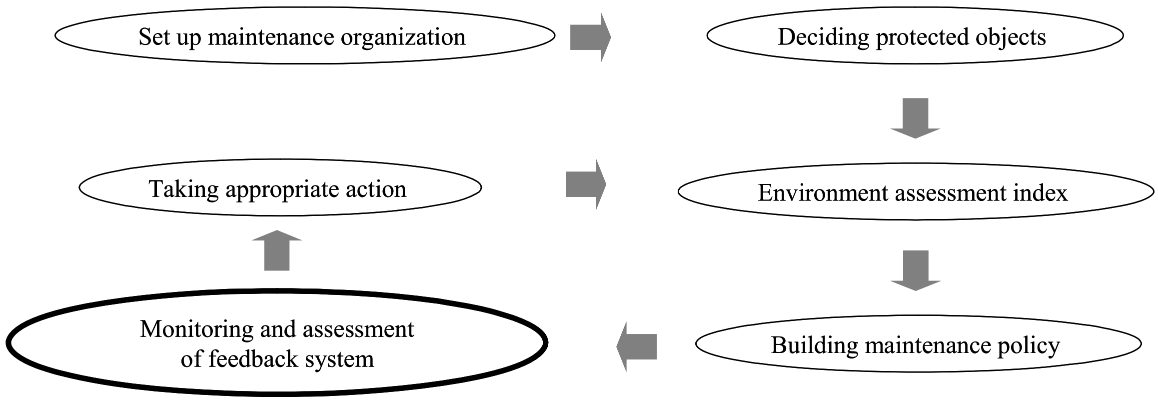

Figure 4. Maintenance process

6. CONCLUSIONS

Taiwan has promoted EE quite positively in recent years. Many successful cases are presented on the PCC website, which is available for access by all interested parties [1]. Because EE emphasizes tailoring projects to local circumstances and adopting site materials, each EE project is unique. Each project involves a different environment, particular materials, unique ecology, and so on, so each must adopt different techniques to meet its objectives. Therefore, thorough assessment of all relevant information in the plan-design stage is a key determinant of whether or not an EE project is successful.

This study proposed an integrated approach for organizing the processes of building EE, and then evaluating important quality items in each stage. Engineers can use this structure and check items at every stage in order to achieve long-lasting preservation of the environment.

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