LIFE-CYCLE MANAGEMENT OF SUSTAINABLE PUBLIC INFRASTRUCTURE

Dr. Jenn-Chuan Chern
Deputy Minister, Public Construction Commission
Executive Yuan, Republic of China
and
Distinguished Professor, Department of Civil Engineering,
National Taiwan University, Taipei, Taiwan

Dr. Tony C. Liu
Visiting Research Fellow, Department of Civil Engineering,
National Taiwan University, Taipei, Taiwan

ABSTRACT

With the inevitability of declining non-renewable energy and natural resources and the threat of global climate change, energy saving and carbon reduction are essential survival strategy for the developed and developing countries in the world. The quality and sustainability of a nation's public infrastructure is a critical index of its economic vitality and national competitiveness. To ensure sustainable development of public infrastructure, the Public Construction Commission (PCC), Executive Yuan of Republic of China, issued a white paper and its implementation plan on "Sustainable Public Infrastructure – Energy Saving and Carbon Reduction" in November 2008. This white paper outlines broad principles and policies for achieving the sustainability of public infrastructure.

Based on this white paper, the strategies and practical measures for sustainable development of public infrastructure with the emphasis in energy saving and carbon reduction during the entire life of the infrastructure, including the feasibility phase, planning, design, construction, operation, maintenance, and, at the end of service life, demolition and reuse are presented. The evaluation criteria and implementation plan including the development of the preliminary assessment indicators for sustainable construction are provided. Two successful stories of implementing energy saving and carbon reduction measures in planning, design, and construction of two recent public works projects in Taiwan are presented.

INTRODUCTION

According to Intergovernmental Panel on Climate Change (IPCC) 2007 Report [Ref 1], continued greenhouse gas emissions at or above current rates would cause further warming and induce climate changes during 21st century that would very likely be larger than those observed during the 20th century. Global warming and climate change would result in frequent extreme weather events (such as heavy rains, severe storms, floods and droughts) and sea level rise causing flooding in shorelines.

The current population in Taiwan is approximately 0.4% of the total world population. However, Taiwan emits about 1% of the total world CO_2 emissions. According to the International Energy Agency (IEA) report [Ref 2], the CO_2 emissions in Taiwan were 11.26 tons per person in 2007. These CO_2 emissions were ranked 18th in the world and the highest in the Asian regions. Therefore, there is an urgent need in Taiwan to reduce the "green house" emissions, particularly carbon dioxide to combat global warming.

Many bridges, highways, buildings, dams, coastal structures, and other key elements of a modern society in Taiwan are approaching or exceeding their design life. In addition, excessive demand, severe natural environment (i.e., frequent earthquakes and typhoons), misuse, inadequate maintenance, poor management policy take their toll [Ref 3]. The current public infrastructure conditions and management practices are insufficient to meet the demands of future economic growth and development.

To ensure sustainable development of public infrastructure and to protect the environment, the Public Construction Commission (PCC), Executive Yuan of Republic of China, issued a white paper and its implementation plan on "Sustainable Public Infrastructure – Energy Saving and Carbon Reduction" [Ref 4] in November 2008. This white paper outlines broad principles and policies for achieving the sustainability of public infrastructure. The vision is to reduce the carbon footprint in 2016 to the level of 2008 and to achieve the carbon footprint in 2025 to the level of the year of 2000.

Based on this white paper, the strategies and practical measures for sustainable development of public infrastructure with the emphasis in energy saving and carbon reduction during the entire life of the infrastructure, including the feasibility phase, planning, design, construction, operation, maintenance, and, at the end of service life, demolition and reuse are presented. The evaluation criteria and implementation plan including the development of the preliminary assessment indicators for sustainable construction are provided.

SUSTAINABLE PUBLIC INFRASTRUCTURE

The sustainable development is frequently defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [Ref 5]. By this definition, the sustainable public infrastructure is the infrastructure that is planned, designed, constructed, operated, and maintained in the manner that encompasses the following three general elements:

- Environmental stewardship,
- Social responsibility, and
- Economic prosperity.

More specifically, sustainable public infrastructure should have the following characteristics: high-performance, durable and long-service life, safety, economy, resources efficiency, preservation of natural environment and cultural heritage, and equality of regional economic development.

LIFE-CYCLE MANAGEMENT OF SUSTAINABLE PUBLIC INFRASTRUCTURE

The following paragraphs present the life-cycle management of sustainable public infrastructure with the emphasis in energy saving and carbon reduction. The life cycle of a public works project includes the feasibility phase, planning and design, construction, operation and maintenance, and, at the end of the service life, demolition and reuse.

Feasibility Phase

A feasibility study needs to be authentic and thorough as it is the basis for government making an important investment decision. It is important to establish the energy saving and carbon reduction goals during the feasibility study of a public works project. Major efforts during the feasibility phase include

(1) Define the needs and the scope of the proposed project for meeting the government’s strategic objective and anticipated economic development. This may involve an inventory analysis of evaluating the conditions and performance adequacies of the existing project(s).

(2) Evaluate all solution options including the advantages and disadvantages of each option, including the option to repair and rehabilitation of the existing project.

(3) Estimate the life-cycle costs over the whole life of the project. In addition to the design and construction costs, it is very important to include adequate operating costs, maintenance and management costs for the life of the project.

(4) Establish the energy saving and carbon reduction goals or substituting alternatives if the goals are unattainable for the particular project.

Planning and Design Phase

Planning and design are multi-disciplinary processes that generally involve architects, engineers, as well as environmental scientists to address environmental issues. Energy saving and carbon reduction measures should be addressed during this phase. These measures may include the use of performance-based design, least-dimension and least-weight design, application of high-performance materials, use of recycled materials, as well as specifying high efficiency electrical equipment and renewable energies. Specifically, the major effects include:

(1) Develop and use performance-based design and specifications to improve the quality of the design and construction.

(2) Use high-performance, high-strength materials for least-dimension and least-weight design strategies. These strategies reduce the size and weight of the project and reduce the amount of construction materials and costs.

(3) Use sustainable construction materials and products by evaluating several characteristics such as reused and recycled content, high recyclability, and durability. Use locally available materials and products will reduce transportation costs and energy.

(4) Maximum use of supplementary cementing materials such as fly ash, ground-granulated blast-furnace slag, and silica fume to replace some of the portland cement in concrete construction. These supplementary cementing materials not only recover industrial byproduct, generate no or fewer CO_2 emissions, avoid disposal, but also improve durability [Ref 6].

(5) Incorporate environmental (green) design to enhance and protect the natural environment

(6) Planning and design efficient electrical system and minimize the electric loads for heating and air conditioning system, lighting requirements, and other electrical equipment. Planning and design of renewable energies in public works projects should also be considered.

<u>Construction Phase</u>

During the construction phase, the energy saving and carbon reduction measures may include reduction and reuse of excavation materials and construction wastes, use of energy efficient construction equipment, protect the environment during the construction. Specific measures are as follows.

(1) Minimize the amounts of excavation materials, balance the soil excavation and backfill layout, and reduce and reuse excavation materials and construction wastes.

(2) Enforce adequate construction quality assurance and quality control to ensure durable and quality construction project and therefore, minimize future repair requirements.

(3) Use energy efficient and high performance construction equipment.

(4) Promote the use of precast and construction automation technologies.

(5) Protect the environment by providing and protecting habitats during construction. Preserve and enhance bio-diversity and wetland ecosystem.

Operation and Maintenance Phase

To ensure operational adequacy and energy saving and carbon reduction during the operation and maintenance phase, the following efforts need to be carried out.

(1) Develop a comprehensive management system, including operation and maintenance policies and regulations, budgeting, inspection requirements, and performance monitoring and evaluation system.

(2) Develop and maintain a performance database. This database should include maintenance records, condition assessment data, and other items that provide appropriate and timely information for decision making.

(3) Provide adequate funding and resources for maintenance, periodic inspection and evaluation, and proper repair and rehabilitation to achieve maximum usage of the facility.

(4) Perform periodic inspection, evaluation, and proper maintenance can enhance and extend the service life of the project. Extending service life instead of removal and rebuild not only requires less natural resources and energy but also minimizes environmental impacts. Poor-quality and poorly maintained structures will deteriorate prematurely and frequently require costly repairs and result in waste of natural resources and energy.

End of Service Life

When the project no longer serves the intended purposes or it is not cost effective to repair or rehabilitate, the project may be decommissioned and removed. Reuse and recycle the demolition materials will save energy and natural resources. For example, use inert demolition materials as a base course for pavement construction keep demolition materials out of landfills and reduce energy and costs.

IMPLEMENTATION PLAN

Development of Assessment Indicators

In order to provide a means for assessing the progress in sustainable construction, a preliminary framework for sustainable construction assessment methodology is developed [Ref 7]. Figure 1 shows the preliminary framework for a sustainable construction indicator system. As shown in Figure 1, it consists of 5 layers, i.e., the indicator, the indicator category, the core cluster, the theme, and the overall performance. Table 1 describes the content of each theme, the core cluster, and indicator category. Methods for selecting proper indicators in accordance with local constraints, specific features, and national priorities are being developed.

Establishment of SPI Label System

A sustainable public infrastructure (SPI) label system is being established for the purpose of promoting and certifying that a public works project that has incorporated effective or innovative, or both energy saving and carbon reduction measures. Initially, major public works projects will be evaluated and certified with SPI Label and, in the future, all public works projects will be required to be certified with SPI Label.

Public Infrastructure Review and Approval Processes

The current public infrastructure design and budget review and approval processes will be re-evaluated. The energy saving and carbon reduction measures for a proposed public works project will be the important criteria to be evaluated during the review and approval process. Adequate maintenance and management system for the proposed public works project will also be evaluated to ensure long service life of the project.

Technology Transfer Initiatives

Continuing efforts will be made to synthesize and publish useful information on new and improved energy saving and carbon reduction measures for sustainable public infrastructure. Relevant research results, foreign developments, and field experience will be analyzed and documented. An integrated knowledge system (e.g., a computerized database) for sustainable public infrastructure will be planned, built, and maintained at a national level. Regularly scheduled training courses and workshops will be conducted for personnel involved in public works projects.

Establishment of a New "Energy Saving and Carbon Reduction" Award Category

A new "Energy Saving and Carbon Reduction" award category was added to the Annual Public Infrastructure Golden Award Program in 2008 to promote the awareness of the importance of energy saving and carbon reduction in public works projects.

SUCCESSFUL STORIES

Two successful stories of implementing energy saving and carbon reduction measures in planning, design, and construction of two recent public works projects in Taiwan are presented.

1. Sports Complex for the 21st Summer Deaflympics, 2009

The design of the sports complex for the 21st Summer Deaflympics in Taipei started in December 2006 and the construction is to be completed in April 2009. This sports complex consists of three major structures: main stadium, sports center, and warm-up field (Fig. 2). The energy saving and carbon reduction measures implemented in this project include:

a. Replace 20% of portland cement with slag in concrete mixtures. The total portland cement and slag used in this project were 2,520 tons and 473 tons, respectively. Since each ton of cement and slag contribute about 880 kg/ton and 68 kg of CO2, respectively, the slag replacement reduced 384 tons of CO2 emissions in this project. The slag concrete not only meets the strength requirements but also enhances the durability of concrete.
b. Use a special pre-mixed grouting material. Production of this special pre-mixed grouting material generates approximately 30 % fewer CO2 emissions as compared to the conventional cement grouts. In this sport complex, the total CO2 reduction was estimated to be 100 ton by using the pre-mixed grouting material.
c. Use of sandwich plates and hollow bricks for roofing shell and exterior walls. This energy efficient design reduced heat loads in the summer. As a result, the annual energy savings for air conditioning are estimated to be 786,000 kw-h. This would result in annual CO2 reduction of approximately 500 tons.
d. Use of high-strength steel reinforcement and welded steel wire mesh. Use of high-strength steel reinforcement and welded steel wire mesh in the design reduces the amount of conventional steel by 30-40%. In addition, the use the patented multi-spiral shear reinforcement design instead of the conventional stirrups in rectangular columns reduces the amount of steel by 30-50% and therefore, saving 30-50% of energy for producing the steel reinforcement.

2. Lu-Jiao Creek Wetland Restoration Project

This 16-acre wetland, located in Taipei Country, has a daily flow of 12,000 tons of water and sewage. Innovative designs of this wetland restoration project resulted in carbon reduction of 86,000 ton of CO2 emissions annually. The innovative designs included:

a. Gravity water intake system. The gravity water intake system requires no energy and therefore saves 160,000 kw-h of electricity annually if the conventional pumped intake system is used. This would result in reducing 100 tons of CO2 emissions.
b. Natural sewer treatment system. When compared with the traditional sewer treatment plant, the innovative natural sewer treatment system will save annual operation and maintenance cost of $500,000 USD and will have the annul energy saving of 1.97 million kw-h that is equivalent to reduction of 83,000 tons of CO2 emissions.
c. Wetland Vegetations. Various kinds of native vegetations were planted in the wetland. The annual CO2 absorption by wetland vegetations is estimated to be 900 tons.
d. Gravel infiltration prevention system. The design of gravel infiltration prevention system instead of the conventional infiltration prevention materials and methods would result in carbon reduction of approximately 2000 tons.

CONCLUSIONS

With the inevitability of declining non-renewable energy and the threat of global climate change, energy saving and carbon reduction are essential survival strategy for the developed and developing countries in the world. To keep pace with global trends, Taiwan Government has made a strong commitment to sustainable development by publishing a white paper that outlines broad principles and practical measures for energy saving and carbon reductions for the entire life cycle of the public infrastructure. By implementing these principles and measures for energy saving and carbon reduction for sustainable public infrastructure, it will ensure the economic growth and national competitiveness and will foster the well-being of current and future generations.

ACKNOWLEDGEMENT

The views expressed in this paper are those of the authors and do not necessarily reflect the policies of the Public Construction Commission and Government of Republic of China (Taiwan).

REFERENCES

1. “Climate Change 2007: Synthesis Report,” Intergovernmental Panel on Climate Change (IPCC), Nov. 2007

2. “CO2 Emissions from Fuel Combustion,: 2008-Edition, International Energy Agency (IEA)

3. Liu, Tony C. and Chern, Jenn-Chuan: “Infrastructure Renewal and Management Research in Taiwan” Paper presented at the International Symposium on Infrastructure and Environment, sponsored by the Society for Social Management Systems, Kochi, Japan, March 6-8, 2008.

4. “Sustainable Public Infrastructure – Energy Saving and Carbon Reduction,” Public Construction Commission, Executive Yuan, Republic of China, Nov 2008 (In Chinese)

5. “ The Brundtland Report,“ World Commission on Environment and Future Development, “Our Common Future,” 1987

6. Liu, Tony C. and Chern, Jenn-Chuan: “Sustainable Concrete Technology for the 21st Century,” Proceedings of 2008 KCI-JCI-TCI Symposium, Kintex, Korea, November 6-8, 2008

7. Huang, R. Y. and Hsu, W. T.: “Developing Appraisal Indicators for Sustainable Construction,” Proceedings, Eleventh East Asia-Pacific Conference on Structural Engineering & Construction (EASEC-11), Nov 19-21, 2008, Taipei, Taiwan.

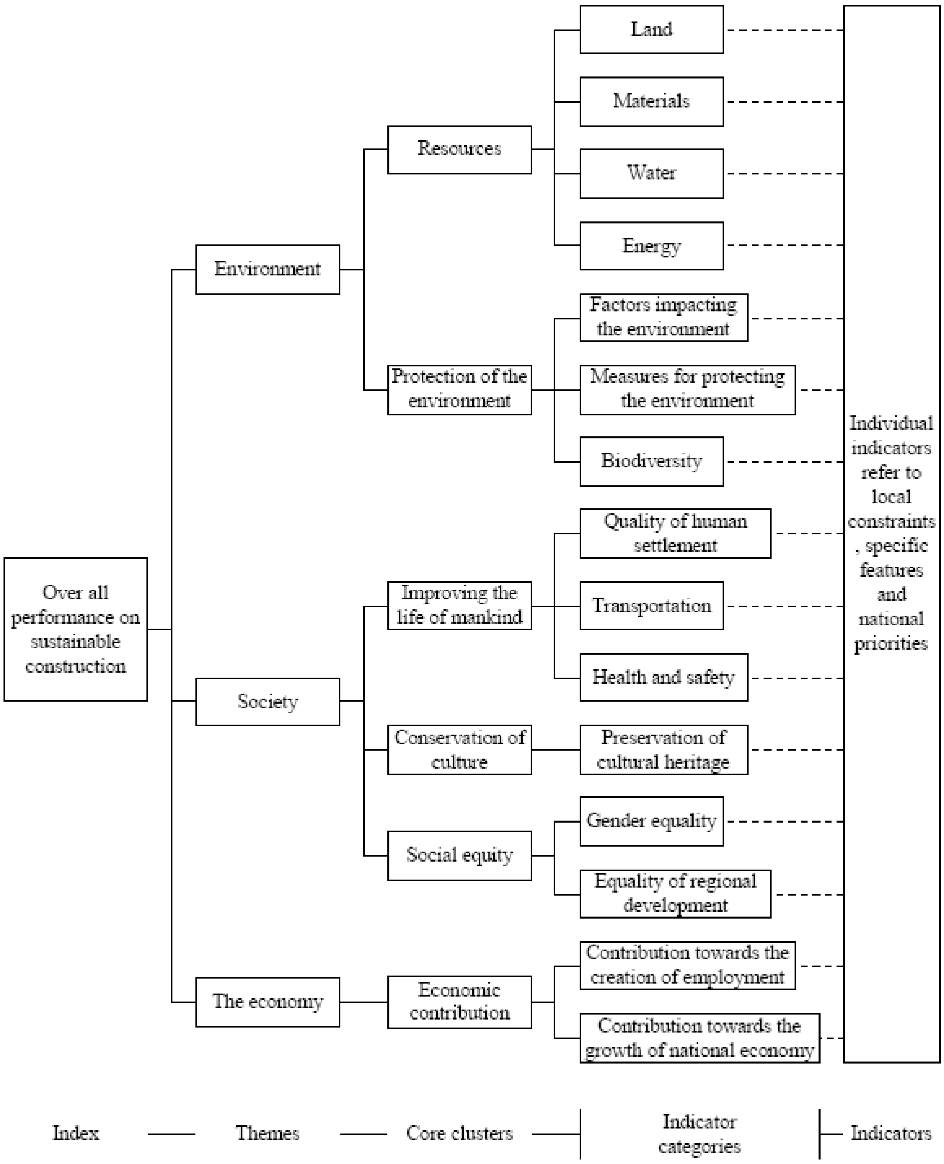

Figure 1 Framework of the sustainable construction indicator system [Ref 7]

Figure 2 Sports Complex for the 21st Summer Deaflympics, 2009

Table 1 Description of themes, core clusters, and indicator categories [Ref 7]

Theme/Core cluster /Indicator category	Description
Environment	Construction based on resource efficient, ecological principles.
Resources	Evaluation of resource consumption in construction, including land, materials, water, and energy use.
Land	Efficient use of land, including conservation of open spaces and rural settlement, prevention of urban decline, reduction of sprawl, etc.
Materials	Selection of materials based on environmental performance, including the use of renewable materials, reducing the use of natural resources, recycling, etc.
Water	Promoting efficient water use, including reducing the use of high quality drinking water, relying on rainwater/gray water, etc.
Energy	Promoting energy efficiency, including the use of energy saving measures, use of renewable energies, etc.
Protection of the environment	Evaluating the effort taken to protect the environment during construction, including reducing impact on the environment, measures for protecting the environment, and biodiversity.
Factors impacting the environment	Factors impacting the environment can include air pollution, water pollution, sound pollution, etc., resulting from construction.
Measures for protecting the environment	Measures executed for protecting the environment, including construction procedures, and construction goals.
Biodiversity	Construction work has a direct impact on biodiversity through the fragmentation of natural areas and ecosystems. With sustainable construction, how to conserve natural areas and promote biodiversity should be considered.
Society	The creation and responsible management of a healthy building environment.
Improving the life of mankind	Evaluate efforts taken to improve the life of mankind via construction, including the quality of human settlements, transportation, health and safety, etc.
Quality of human settlement	The quality of human settlements including living space, the quality of the indoor environment, and infrastructure such as water supply systems, electrical power supply systems, etc.
Transportation	Transportation infrastructure, including roads, railways, and rapid transit systems are very important to sustainable development in both the society and the economy, and should be continuously improved.
Health and safety	In sustainable construction, importance is attached to the health and safety of human life, preservation of the environment, including more open space for leisure activities, preventing the occurrence of environmental disasters, promoting a safe and healthy working environment in construction sites, etc.
Conservation of culture	Evaluate efforts taken towards the conservation of culture during construction.
Preservation of cultural heritage	The maintenance and renovation of our cultural heritage.
Social equality	Evaluate the effort taken to maintain social equality in construction, including gender equality, racial equality, equality of regional development, etc.
Gender equality	Gender equality in construction work, including the equality of employment opportunities, salary, etc., between males and females.
Equality of regional development	The development of regions will differ from each other in terms of investment in infrastructure. Sustainable construction should serve to promote the equality of regional development.
The economy	Construction should first be based on resource efficient and ecological principles, and must then promote continuously promote economic
Economic contribution	Evaluate the contribution of construction towards the development of the

Table 1 Description of themes, core clusters, and indicator categories (Cont'd) [Ref 7]

Theme/Core cluster /Indicator category	Description
	economy, including economic growth, creation of employment opportunities, public-private partnerships (PPPs), etc.
Contribution towards the creation of employment	The construction industry is labour–intensive, and thus contributes to the creation of employment opportunities and alleviates poverty. Sustainable construction should attach importance to human resources, provide sustainable work opportunities and attract human resources to the construction industry.
Contribution towards growth of the national economy	Evaluate construction's contribution on the growth of the national economy.