



Construction Industry Institute®

Sustainable Industrial Construction

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SUSTAINABLE INDUSTRIAL CONSTRUCTION

by

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Construction Industry Institute
The University of Texas at Austin

Under the Guidance of
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Sustainable Design and Construction for Industrial Construction

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EXECUTIVE SUMMARY

This report defines the concept of sustainable development for members of the industrial construction industry. Sustainable development practices are discussed along with information on why they are being used, how they are being used, and what the potential benefits of their use are for engineering and construction industry firms.

The purpose of the proposed research was to write a primer on sustainability in the industrial construction industry. The scope of the research covered research on sustainability in the industrial construction sectors of manufacturing; mining, minerals, and metals; petrochemical; pharmaceutical; power, pulp and paper, and utilities. The objective of the research was to provide members of the industrial construction industry with information on how to evaluate and assess their sustainability and to provide a concise summary of current sustainability practices.

The report provides a summary of 1) current industrial construction sustainability practices, 2) environmental laws and their implications, 3) life cycle cost assessment models, 4) the results of a survey of industrial construction industry experts, and 5) trends and implications including alternative sustainable materials. Several potential assessment resources that were developed during the research are discussed that could be used by firms to evaluate their sustainability practices.

This primer provides information on the techniques and processes that are being used to implement sustainability practices on industrial construction projects and it also provides suggestions for further research.

CHAPTER 1

INTRODUCTION

Implementing sustainable development practices during industrial construction projects is beneficial to the environment, especially in the area of material selection. If designers incorporate materials that are reusable, recyclable, or that require fewer resources to produce and transport, it results in environmental benefits. Some sustainability practices help to reduce energy consumption during construction and operation as does the use of renewable energy alternative technologies during the construction of projects. In the area of waste management sustainability considerations include producing less waste and recycling more waste. Pollution reduction involves having less toxic materials in the products used for construction and also reducing noise and spatial pollution. During the deconstruction of projects the materials that are removed from structures should be recycled or reused rather than disposed of in landfills.

1.1 PROBLEM STATEMENT

Industrial construction projects generate pollution and hazardous wastes and also may negatively impact the environment of the surrounding community. Members of the industrial construction industry would benefit from having access to information on how to incorporate sustainability development practices during both the design stage and the construction of projects. The reputation management of firms is enhanced when its members have access to information that helps to generate more informed decisions on whether to implement sustainable practices on projects, on how to determine the economic, social, and environmental impact of implementing sustainable practices, and on how to determine whether the implementation of sustainability development practices is warranted.

On industrial construction projects the areas that would benefit the most from implementing sustainability practices include:

- Design modifications
- Material production
- Material transportation
- Recourse efficiency
- The selection of materials that are environmentally neutral materials
- Alternative energy sources
- Alternative construction equipment and fuel sources
- Methods for complying with government regulations
- Supplier and vendor social responsibility
- Social and community impacts of projects.
- Production operations

The Construction Industry Institute Research Team 250 *Design and Construction for Sustainability in Industrial Construction* investigated methods for preventing:

- Environmental degradation.
- The creation of hazardous wastes that are toxic to human beings.

- The filling of landfills with toxic substances.
- The creation of greenhouse gases.
- The use of nonrenewable resources.
- Pollution that damages the environment.
- The shortage of construction materials such as wood, steel, and cement.

1.2 OBJECTIVES OF THE RESEARCH

The objective of the research was to investigate sustainable development practices that are used during the design and construction of industrial facilities in order to provide members of scientific and industrial communities with current information that will help increase their understanding of sustainable development practices. Three other subobjectives of the research were to 1) provide information on the costs and benefits of applying sustainable development practices to industrial construction projects, 2) develop a sustainability development metric for assessing sustainability practices on industrial construction projects, and 3) develop recommendations on areas for further research.

To achieve the objectives the research team investigated how to 1) make more informed decisions on whether to implement sustainable practices on projects, 2) determine the economic impact of implementing sustainable practices, 3) determine social and environmental benefits, and 4) determine whether implementing sustainable development practices has a positive effect on reputation management.

1.3 PURPOSE OF THE RESEARCH

The main purpose of the proposed research was to gather information on sustainable development practices in industrial construction from existing research and from members of the industrial construction industry.

The research was conducted to provide members of the engineering and construction industry with 1) information on the types of sustainability practices that are being implemented and on why they are being implemented on construction projects and 2) to assist in their decision making processes regarding the implementation and evaluation of sustainable practices on industrial construction projects.

1.3.1 The Research Hypothesis

The research also was conducted in order to either verify or refute the hypothesis on *whether it is feasible to implement sustainable development practices on industrial construction projects*.

1.4 SCOPE OF THE RESEARCH

Numerous research projects have summarized sustainable development practices that are used for building construction projects including residential, commercial, and institutional construction projects. The United States Green Building Council (USGBC) developed the *Leadership in Energy and Environmental Design* (LEED) metric system that is currently being used for certifying building construction projects. A copy of the LEED Metric is available at the USGBC web site www.usgbc.org and is also included in the Los Alamos National Laboratories Sustainable Design Guide on pages 227-234 (LANL, 2002).

The Council on Tall Buildings and Urban Habitat (CTBUH) is currently working on a tall-building sustainability guideline that could be used, or required by governments or clients, for assessing the sustainability of high-rise construction projects (Engineering News Record, March 17, 2008b).

Since the USGBC and the CYBUH are already working on assessment methods and metrics for the building industry the scope of this research only focused on the global industrial construction sector.

The Sustainability for Industrial Construction research project investigated the following industrial construction sectors:

- a) Manufacturing
- b) Mining, Minerals, and Metals
- c) Petrochemical
- d) Pharmaceutical
- e) Power
- f) Pulp and Paper
- g) Utilities

1.4.1 Limitations of the Study

The research was limited to examining journal publications and other articles that were written in English, Russian, Turkish, and Spanish or that were translated into English. Additional data were collected from industrial construction industry professionals using a knowledge acquisition system. The survey participants included members of the industrial construction industry who have had experience in implementing sustainable development practices on industrial construction projects. The surveys were completed by members of both CII members companies and non-CII companies.

The *International Organization for Standardization* (ISO) produced the ISO 14,000 series of standards that addresses environmental management systems and that provide information for firms on the procedure for certification in the area of environmental management systems. Since the ISO has already developed environmental management systems standards they will not be discussed in this document except as they apply to industrial construction projects. The ISO 14,001 Standard is similar to the *British Standard - BS 7750* (Ball, 2002).

1.5 DEFINITIONS

This section provides definitions for some of the common terms that are used in relation to sustainability in industrial construction.

1.5.1 Sustainability

“*Sustainability* is said to be based on five pillars: conservation of nature, health and safety, reduced use of materials, social ecology, and cultural ecology” (Cywinski, 2001 p. 13). The last two issues are related to education and knowledge, ethics and culture and values of heritage. Other areas of sustainability include: “management and business practices, design technology and procedures, construction methods and equipment, materials and systems, and public and government policy. A list of sustainability linked environmental factors was generated: energy, building ecology, air-

water-landscaping, waste management, cultural change, and behavioral issues” (Cywinski, 1996 p.15).

1.5.2 Sustainable Development

Sustainable development became a mainstream topic when in 1995 the *World Business Council on Sustainable Development (WBCSD)* was formed that included 160 international companies from more than thirty countries. Members of the WBCSD determined that the use of eco-efficiency as a tool to measure environmental sustainability performance would help companies to be able to determine whether they were contributing to sustainable development (Bidwell and Verfaillie, 2000). During this same time period a Swedish environmental organization, the First Step, started promoting “organizational transformation as a key element for society to shift towards sustainable development” (Bradbury and Clair, 1999).

A *Sustainable Development Strategy* for the United Kingdom was created by the government in 1999. At this time the U.K. government also developed a definition for industrial sustainability, “The objectives are social progress which recognizes the needs of everyone, effective protection of the environment, prudent use of natural resources and lastly maintenance of high and stable levels of economic growth and employment” (Paramanathan et al., 2004).

The Institute for Manufacturing at the University of Cambridge developed a definition for *industrial sustainability* that is “conceptualization, design, and manufacture of goods and services that meet the needs of the present generation while not diminishing economic, social, and environmental opportunity in the long term” (Paramanathan et al, 2003).

Sustainable development has been defined in many ways, and one definition characterizes it as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1986). Another definition is “a dynamic process which enables all people to realize their potential and to improve their quality of life in ways which simultaneously protect and enhance the Earth’s life support systems” (Leadbitter, 2002 p. 2197).

Another definition for sustainable development is “the process of moving towards sustainability” (Leadbitter, 2002). In Japan, it is referred to as *environment symbiosis building* or *environmental conscious building* (Cywinski, 2001). In Finland, “according to the *Finnish National Commission on Sustainable Development (FNCSO)*, there are three practical dimensions to sustainable development the ecological, municipal, and cultural dimensions” (European Commission Enterprise, 2001a p. 1).

Other definitions for sustainable development include “a system of changes in public attitude and policy through which the population and vital activities of a community may be continued into the indefinite future without robbing the community of its usable resources” (Cywinski, 2001 p. 13). “A process of change in which the direction of investment, the orientation of technology, the allocation of resources, and the development and functioning of institutions meet present needs and aspirations without endangering the capacity of natural systems to absorb the effects of human activities, and without compromising the ability of future generations to meet their own

needs and aspirations” (Cywinski, 2001 p. 14). *Economic development* “is defined as ethical and wholesome economic growth” (Chong, 2006 p. CT-007-1).

1.5.3 Corporate Sustainability and Corporate Social Responsibility

Corporate sustainability “recognizes that corporate growth and profitability are important, it also requires the corporation to pursue societal goals, specifically those relating to sustainable development — environmental protection, social justice and equity, and economic development” (Wilson, 2003 p. 1). Another definition for corporate sustainability is “a business approach by companies to consider not only economical needs in their strategies and practices, but also environmental needs. It is the opportunity for businesses to improve their profitability, competitiveness, and market share without compromising resources for future generations” (12manage, 2007).

Corporate social responsibility is defined as “the responsibility of multinationals to behave fairly in host communities and to reduce the effects of industrial development in the host community” (Chong, 2006 p. 4). “Corporate Social Responsibility deals with the role of business in society. Its basic premise is that corporate managers have an ethical obligation to consider and address the needs of society, not just to act solely in the interests of the shareholders or their own self-interest” (Wilson, 2003 p. 2).

1.5.4 Sustainable Construction

Sustainable construction involves “creating construction items using best-practice clean and resource-efficient techniques from the extraction of the raw materials to the demolition and disposal of its components” (Ofori, 2000 p. 196). According to the European Union publication *Proposals for a Response to the Challenges of Sustainable Construction* sustainable construction “is the set of processes by which a profitable and competitive industry delivers built assets (buildings, structures, supporting infrastructure and their immediate surroundings) which in turn (European Union, 2001b p. 1):

- Enhance the quality of life and offer customer satisfaction.
- Offer flexibility and the potential to cater to user changes in the future.
- Provide and support desirable natural and social environments.
- Increase investment in people and equipment for a competitive economy.
- Achieve higher growth whilst reducing pollution and maximizing the efficient use of resources.
- Share the benefits of growth more widely and more fairly.
- Improve towns and protecting the quality of the countryside.
- Contribute to sustainable development internationally.

1.5.5 Supply Chain Management and Integrated Chain Management

One definition for *supply chain management* (SCM) is “the integration of key business processes from end user through original supplier that provides products, services, and information that add value for customers and other stakeholders” (Lambert et al., 1998 p. 1).

Integrated chain management has been defined by the Task Force of Integrated Chain Management of the Dutch Environment Ministry as “the management of material flows, in chains caused by social activities, with respect to the environmental space

boundaries” (Heeres et al., 2004 p. 985). Managing material flow should lead to achieving the following three objectives (Heeres et al., 2004 p. 293):

- Reduce the use of non-renewable resources (fossil fuels) and stimulate the use of sustainable energy as much as possible.
- Keep the balance in the process of use and production of renewable resources. This means making sure that one does not use more of a particular resource in a year than the amount of the resource produced in that same year.
- Keep renewable and non-renewable resources as long as possible in the material cycles, unless this is not environmentally desirable.

1.5.6 Environmental Collaborations

Environmental collaborations have been defined as “two or more parties working together in relation to natural environmental issues, where at least one of the parties in an organization is from industry, and another, a non-profit organization that has an objective of environmental conservation” (Fiedler, 2007 p. 410). One example of an environmental collaboration is Greenpeace that is working with firms that are involved in the development of nuclear power plants to create nuclear power plants that are environmentally acceptable to society.

The objective of environmental collaborations is to build a better quality of life and the main goals that have to be pursued in order to achieve this objective are (European Commission Enterprise, 2001b p. 1):

- Re-using existing built assets.
- Designing for minimum waste.
- Minimising energy use throughout the life cycle.
- Avoiding pollution.
- Adding to bio-diversity.
- Conserving water resources.
- Respecting people and communities.

1.5.7 The Triple Bottom Line

The *Triple Bottom Line* - economic, environmental, and social values - in design and construction includes approaches such as: "Design for the environment, context sensitive designs, value engineering, life-cycle cost analysis, and Leadership in Energy and Environmental Design (LEED) certification for projects. Sustainable construction techniques include implementing a sustainable design, meeting or exceeding sustainable design specifications, developing strategies to minimize and reuse construction waste and spoils, optimizing asset efficiency, and pursuing the highest level of LEED certification possible" (Samaras, 2004). The term *triple bottom line* was first used by Elkington in 1997 in his consultancy Sustain – Ability. According to Paramanathan, Furrukh, Phaal, and Probert, in *Implementing Industrial Sustainability: The Research Issues in Technology Management*, the “health of the global ecosystems represents the ultimate bottom line” (Paramanathan et al., 2004 p. 527).

1.5.8 Stakeholders

The *stakeholders* in industrial sustainability are “the individuals or groups that affect, or are affected by, an organization: those that have a legitimate interest in its activities and to whom the organization owes an account of its conduct” (Paramanathan et al., 2004 p. 528).

1.5.9 Industrial Ecology

Another topic of concern related to sustainable development is *industrial ecology*, defined as the “study of physical, chemical, and biological interactions and interrelationships both within and between industrial and ecological systems” (Basu and Van Zyl, 2006 p. 299). According to Basu and Van Zyl in the article *Industrial Ecology Framework for Achieving Cleaner Production in the Mining and Minerals Industry* (2006 p. 301) “the aim of industrial ecology is to interpret and adapt an understanding of the natural system and apply it to the design of the manmade system, in order to achieve a pattern of industrialization that is not only more efficient, but that is intrinsically adjusted to the tolerances and characteristics of the natural system. The emphasis is on forms of technology that work with natural systems, not against them. Applied to industrial ecology is an integrated management and technical program including (Basu and Van Zyl, 2006 p. 301):

- The creation of industrial ecosystems.
- Balancing industrial input and output to natural ecosystem capacity.
- Dematerialization of industrial output.
- Improving the metabolic pathways of industrial processes and material use.
- Policy alignment with a long-term perspective of industrial ecosystem evolution.

In the article, *Industrial Ecology Framework for Achieving Cleaner Production in the Mining and Minerals Industry*, Basu and Dirk summarize industrial ecology as “the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industry system be viewed not in isolation from its surrounding systems, but in concert with them. It is a system view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to product, to waste product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital” (Basu and Van Zyl, 2006 p. 303).

1.5.10 Pollution Prevention

Pollution prevention is defined by the Environmental Protection Agency (EPA) as “the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous materials, energy, water, or other resources and practices that protect natural resources through conservation or more efficient use” (EPA, 2007 p. 1).

1.5.11 Environmental Management

Environmental management as used in the ISO 1,4000 standards “means what an organization does to minimize harmful effects on the environment caused by its activities” (Ball, 2002 p. 421). In the ISO 14,000 series of standards there are standards

that are specific to *life cycle cost assessment* (LCCA), which means to “analyze the environmental impacts of a material from cradle to grave” (Ball, 2002 p. 426).

1.5.12 Other Terms Related to Sustainable Development

Other terms that are used in relation to sustainable development include (Paramanathan et al., 2004 p. 527):

- Design for sustainability including:
 - o full life cycle concepts
 - o design for assemble and disassembly
 - o design for extended life, and for reuse/remanufacturing/recycling
- Product development sustainability
- Design for manufacture
- Design for assembly
- Sustainable quality management (SQM)
- Quality function development (QFD):
- Design for sustainability that includes:
 - o full life cycle concepts
 - o design for assembly and disassembly
 - o design for extended life
 - o design for reuse/remanufacturing/recycling
- Product development sustainability
- Design for manufacture
- Design for assembly
- Sustainable quality management (SQM)
- Quality function development (QFD)

Appendix I provides a list of some of the more commonly used acronyms and organizations that are frequently used in relation to sustainability topics.

1.6 BACKGROUND INFORMATION

This section provides information about the drivers that are influencing the implementation of sustainable development practices, on sustainability development in the building sector and in the industrial construction sector.

1.6.1 Foreign Government Objectives

The most far-reaching objectives to have been adopted related to sustainable development were adopted by the *Swedish Parliament* (the Riksdag) in 1999 and they include 15 environmental objectives (European Commission Enterprise, 2001a):

- Clean air
- High-quality groundwater
- Sustainable lakes and watercourses
- Flourishing wetlands
- A balanced marine environment, sustainable coastal areas and archipelagos,
- No eutrophication
- Natural acidification only
- Sustainable forests

- A varied agricultural landscape
- A magnificent mountain landscape
- A good urban environment
- A non-toxic environment
- A safe radiation environment
- A protective ozone layer
- Limited influence on climate

There are five Dutch Environmental value standards (European Commission, 2001a p. 1):

- 1) raw materials
- 2) emissions
- 3) energy
- 4) waste
- 5) nuisance

In addition, the Dutch government recognizes 13 types of environmental impacts (European Commission Enterprise, 2001a p. 1):

- depletion of raw materials
- depletion of fuel resources
- the greenhouse effect
- damage to the ozone layer
- summer smog
- human toxicity
- ecotoxicity in water
- acidification
- eutrophication
- use of non-renewable energy sources
- waste
- hazardous waste
- radioactive waste

In Holland when members of firms are assessing the five *Dutch Environmental Values*, the 13 types of environmental impacts are assessed and weighted to determine an overall value.

1.6.2 Barriers to Implementing Sustainability Practices

It is difficult to implement sustainable development practices in the industrial construction industry because the amount of time that is spent at construction sites is limited and there is pressure to complete projects as quickly as possible. In addition, the divisions between the construction trades make it harder to communicate sustainable practices and to ensure that they are being properly implemented on projects. One other barrier is the reluctance to innovate on construction projects. Liability issues make members of firms hesitant to implement new products or processes (Lindley, 2002).

“There is ample evidence that the primary reasons engineers practice green engineering is because it is good for business. In one study, fifty-four companies who had professed to be *green companies* were asked about substituting nontoxic chemicals in the process. Fully two-thirds of these companies said that they would do so as long as the product cost did not increase by more than 0.1 percent. The other third of the companies would not entertain such substitution if it increased the product cost” (LANL, 2002 p. 7).

1.6.3 Drivers for Implementing Sustainable Development Practices

There are many different drivers that are influencing the implementation of sustainable development practices and some of them are the following:

- Owners
- Non-governmental organizations
- Government legislation
- Public awareness of sustainability issues
- The media
- Competitive differentiation
- Profit
- Quality of life for future generations

Other drivers include (Paramanathan et al., 2004 p. 526):

- Financial gains.
- Enhanced corporate reputation.
- Improved government relations.
- Increased technology and innovation skills.
- Increased risk management skills.
- Brand loyalty.
- Employee loyalty.
- Increased ease of recruitment.

Companies may also avert “serious reputation damage, change the flow of the market demand, and avoid the risk of a boycott or being left behind in stiff competition” (Paramanathan et al., 2004 p. 527). In a survey of consumers in four countries it was determined that consumers would switch brands if a firm was associated with a worthy cause – the U.K. 86 percent, Italy 75 percent, Australia 63 percent, and Belgium 65 percent.

1.6.4 Sustainability in the Building Sector

There are many resources that provide information on sustainable development practices for building construction including the ones that are published by:

- The **Department of Engineering Building Technology Program** - *Energy and the Environmental Guidelines for Construction* (U.S. Department of Energy, 2004).
- The **Los Alamos National Laboratory Sustainability Design Guide** (LANL, 2002).

- The **Chartered Institute of Building (CIOB)** - *Sustainability and the Construction Industry in the United Kingdom* (Chartered Institute of Building, 2004).
- The **United States Green Building Council** – *Leadership in Energy and Environmental Design* (USGBC) (2006).
- The **Environmental Protection Agency** - *Environmental Performance of Building Guidelines* (EPA) (2007).

One organization that has been researching the benefits of implementing sustainable development practices on building projects is the Los Alamos National Laboratory. The *Los Alamos National Laboratory Sustainability Design Guide* provides an example of a Thermal Test Facility (TTF) that is an open-plan laboratory building designed using a high-performance, whole-building approach. The building is a showcase for integrated energy-efficiency features that considerably reduce energy costs. The additional costs for implementing the sustainable design increased costs of construction by only four percent. The energy costs for the TTF are 63 percent less than for other similar buildings built to the Federal Energy Code (10CFR435). The energy cost savings includes a 40 percent reduction in energy consumption and a 30 percent peak power reduction. Approximately 75 percent of the lighting needs are met by using daylight (LANL, 2002).

1.6.5 Sustainability in the Construction Sector

The *Department of Engineering Building Technology Program - Energy and the Environmental Guidelines for Construction* mentions that in order to promote the use of sustainability practices at construction jobsites it is important to (U.S. Department of Energy, 2004):

- Explain methods for protecting vegetation, such as designating access routes and parking.
- Require methods for clearing and grading sites that lowers the impact as much as possible.
- Examine how runoff during construction may affect sites. Consider creating storm water management practices, such as piping systems or retention ponds or tanks that can be used after the building is complete.
- Be sure that the infrastructure for recycling construction and demolition materials is ready and operating from the beginning of projects. Set up an on-site system to collect and sort waste for recycling, or for reuse, and monitor the system consistently throughout all phases of construction.
- Create plans for recycling that set goals to recycle or salvage a minimum of 50 percent (by weight) of construction, demolition, and land clearing waste from construction sites, and aim for a minimum of 75 percent.
- If possible, choose products and materials with minimal or no packaging.
- Obtain materials in the sizes that are necessary, instead of cutting materials to size at jobsites.
- Always monitor the amount of waste being produced during construction and compare it with pre-existing goals and guidelines.

1.6.6 Pollution and Waste Management

The Chartered Institute of Building (CIOB) in the United Kingdom, in its report on *Sustainability and Construction*, states that the starting point for all members of the construction industry who wish to move toward sustainability as a business opportunity should evaluate their operations in four key areas (Chartered Institute of Building, 2004, p. 2):

- **Energy:** reduce energy consumption, be more energy efficient and use renewable energy as well as “alternative technologies”.
- **Materials:** Choose, use, re-use, and recycle materials during design, manufacture, construction, and maintenance.
- **Waste:** Produce as little waste as possible and recycle more.
- **Pollution:** Produce less toxic materials to reduce water and spatial pollution.

The Energy and the Environmental Guidelines for Construction, written by the Department of Engineering Building Technology Program, mentions that in order to promote sustainability at construction jobsites it is important to (U.S. Department of Energy, 2004 p. 1):

- Document a site's existing natural, historical, and cultural features and make specific plans to protect them.
- During the design phase indicate locations for job trailers and equipment.
- Indicate the areas of the site that should be kept free of traffic, equipment, and storage.
- Prohibit clearing of vegetation beyond forty feet from the building perimeter.

1.6.7 Sustainability in the Industrial Construction Sector

Sustainable industrial ecology is another area being explored by members of the manufacturing, construction, and processing industries. Optimal resource consumption is being studied through a framework that integrates different processes, economic and environmental constraints, and health and safety considerations (Basu and Van Zyl, 2006, p. 299).

Increasing energy demands require improved standards and regulations for the industrial construction industry. Sustainability practices should be incorporated into construction projects during the planning stage including the selection of more environmentally friendly materials and technologies, the use of construction processes that utilize less toxic materials and that consume less energy and produce less waste.

Cement is used in all types of construction and, as the article by Basu and Van Zyl, in the article *Industrial Ecology Framework for Achieving Cleaner Production in the Mining and Minerals Industry*, mentions numerous studies on how to improve the efficiency of cement production and on how to minimize toxic emissions from the cement industry (Basu and Van Zyl, 2006).

1.7 ORGANIZATION OF THE REPORT

The following chapters include information on 1) the methodology that was used to collect data for the Sustainable Design and Construction research project, 2) a summary of current sustainability development practices that are being used in the industrial construction sector, 3) information on environmental laws and their implications, 4) examples of economic models that could be used to evaluate sustainability practices, 5) the results obtained from a survey of engineering and construction industry professionals on sustainability development practices on industrial construction projects, 6) information on the trends and implications of using sustainability development practices, and 7) recommendations for further research to help validate the use of sustainability development practices on industrial construction projects.

CHAPTER 2

METHODOLOGY

2.1 INTRODUCTION

In order to collect information on sustainability in industrial construction, and to either verify or refute the hypothesis on *whether it is feasible to implement sustainable development practices on industrial construction projects*, a series of tasks was undertaken that helped to contribute to the body of knowledge related to sustainability development in the industrial construction sector. Each of the tasks is briefly described in this chapter.

2.2 LITERATURE REVIEW OF CURRENT SUSTAINABILITY PRACTICES

In order to investigate sustainability development practices that are used on industrial construction projects, other research projects that addressed this topic were located and analyzed to determine their applicability to industrial construction projects. Information was collected both in the United States and from foreign countries. Articles were located that were written in English, Russian, Spanish, French, and Turkish or that were translated into English. The literature review was divided into different focus areas in order to investigate each of the aspects related to sustainable development. The focus areas that were investigated for the research project were:

1. Environmental impacts and environmental impact statements.
2. The social and community impact of projects.
3. Supplier and vendor environmental and social responsibility including responsible supply chains and procurement.
4. Resource efficiency including reducing energy consumption during construction.
5. Renewable energy.
6. Sustainable design.
7. Material cradle to grave ecological costs including whether materials are reused or recycled, and reducing energy use during the manufacturing and transporting of materials.
8. Environmental impact of production operations.
9. Environmental footprint of structures.
10. Producing less waste.
11. Recycling more waste during construction.
12. Less toxicity in pollution or generating less pollution.
13. Reducing noise and spatial pollution.
14. Deconstruction and the recycling of the by-products of deconstruction.
15. The long-term affects of not considering sustainability during construction.
16. The ISO 14,000 Environmental Management Standards.
17. Compliance with government regulations.

2.3 REVIEW OF GLOBAL ENVIRONMENTAL TREATIES

The environmental treaties that were reviewed for the research included the *United Nations Framework Conventions on Climate Change* (UNFCCC) and:

- The Kyoto Protocol Treaty
- The Basel Convention
- The Rio Declaration
- The Stockholm Convention

2.4 REVIEW OF GOVERNMENT ENVIRONMENTAL REGULATIONS – DOMESTIC AND FOREIGN

Information was collected on sustainable development industrial construction practices from domestic and foreign government agencies including:

- The United States Environmental Protection Agency (EPA)
<http://www.epa.gov>
- Russia - The Federal Service for Hydrometeorology and Environmental Monitoring, http://www.meteorf.ru/en_default.aspx.
- Australia - The Department of the Environment and Heritage
<http://www.environment.sa.gov.au/>.
- India - The Ministry of the Environment and Forests <http://envfor.nic.in/>.
- Japan - The Ministry of the Environment <http://www.env.go.jp/en/>.
- The United Kingdom - The Department for Environment Food and Rural Affairs
<http://www.defra.gov.uk/>.
- Chile - The National Commission on Medio Ambiente
<http://www.conama.cl/portal/1301/channel.html>.
- The Congo - The Ministry of Tourism and Environment <http://www.congo-site.net/v4x/instit/gouvernement/home.php>.
- Kenya - The Ministry of Tourism and Wildlife
<http://www.tourism.go.ke/ministry.nsf>.
- Egypt - The Ministry of State for Environmental Affairs
<http://www.eeaa.gov.eg/English/main/about.asp>.
- Jordan - The Ministry of Municipal and Rural Affairs and the Environment
<http://www.environment.gov.jo/main.html>.

- China - State Environmental Protection Administration
<http://english.sepa.gov.cn/>.
- Saudi Arabia - The Meteorology and Environmental Protection Administration
<http://www.pme.gov.sa/esoon.asp>.

In addition, laws and documents published by domestic and foreign governments that pertain to sustainable development practices in industrial construction were investigated including:

- The United Nations Global Compact.
- The World Business Council for Sustainable Development (WBCSD).
- Spain - The Labor Relations and Social Affairs Committee that is developing a set of recommendations for Corporate Social Responsibility.
- United Kingdom - The Sustainable Development Policy of 2005.
- The French Law on Economic Regulations of 2001.
- The Brazilian Environmental Crimes Law of 1995 that allows executive officers of companies to be sued in criminal court for not meeting environmental health and safety standards.
- The Chilean Clean Production Agreements Environmental Legislation of 1993.
- The Canadian Project Green of 2005 that pertains to the oil and gas industry, thermal production, electrical generation, mining, and manufacturing.
- The Chinese National Committee on Environmental Planning and Coordination (NCEPC).
- The Chinese Division of Development and Construction.
- The German Waste Disposal Act of 1972, the Waste Avoidance and Waste Management Act of 1986, and the Closed Substance Recycle and Waste Management Act of 1986.

2.5 DEVELOPMENT OF THE KNOWLEDGE ACQUISITION SYSTEM

A questionnaire was developed based on the information collected during the literature review and the investigation into global treaties, environmental laws and lawsuits, and the information from government agencies that oversee environmental practices in countries throughout the world. The CII Research Team 250 also provided questions that were incorporated into the questionnaire. Members of Research Team 250 were originally planning to use an interview guide and conduct phone interviews with engineering and construction industry personnel but the interest level in the topic of sustainability in industrial construction kept expanding; therefore, it was determined that

a written questionnaire would be able to capture the knowledge of industrial experts in a manner more conducive to the research investigation.

The questionnaire was designed to include questions that could be answered with “yes”, “no”, or “do not know” responses and if the respondents answered in the affirmative they were provided with additional space to elaborate on their yes answer by providing examples of situations where methods, processes, or ideas were implemented on actual construction projects. The questionnaire included check boxes for answers along with textboxes for written clarification of the checkbox answers. The questionnaire used for the research project is provided in Appendix II.

The survey participants provided information on:

- The sustainability programs being utilized in their firms.
- How sustainability programs are being implemented in their firms.
- How sustainability programs are evaluated.
- Barriers to implementing sustainability programs.
- Drivers to implementation of sustainable development practices.
- The economic benefits of using sustainable development practices.
- The social conditions addressed during construction.
- Sustainable alternatives to traditional construction materials.
- How the benefits of using sustainable practices are measured on projects.
- Techniques used to improve sustainable development.
- The use of innovative sustainable designs or construction components.
- How the wastes being generated during construction projects are being recycled or reused.
- Pollution prevention techniques.
- Whether their firms have a method for measuring metrics related to sustainable objectives.

2.6 DISTRIBUTION OF THE QUESTIONNAIRE

The industry experts that completed the questionnaire included members of the CII Research Team 250 who were selected to participate on this research project because of their expertise on sustainable development and members of the engineering and construction industry that are involved in the implementation of sustainable development practices on industrial construction projects. Some of the engineering and construction industry experts were selected by members of the CII Research Team 250.

The questionnaires were distributed through email, or the U. S. Postal Service, by the academic researcher at Ohio University. The members of Research Team 250 contacted 73 individuals before they were sent questionnaires to determine their willingness to participate in the research project. Surveys were also sent to 150 CII data liaisons, the top 50 sustainable contractors, and 129 firms that perform industrial construction. Each questionnaire that was sent out had a unique company code listed on it and only the front page contained information related to the person filling out the survey and their company affiliation. When the surveys were returned the front page was removed to protect the confidentiality of the information. The remaining portions of

the surveys only contained the company codes. The surveys were not stored on a computer to help protect the confidentiality of the respondents.

2.7 DATA ANALYSIS

The data collected from the literature review and the surveys were summarized by each of the focus areas listed in Section 2.1. Any information that pertained to industrial construction was extracted and summarized for inclusion in the research project.

The questionnaires were analyzed by computing the total number of yes, no, and do not know responses and summarizing the comments supplied by the survey participants using keywords.

2.8 RESULTS OF THE DATA ANALYSIS

After the data was collected and analyzed the results were summarized to evaluate whether the research hypothesis was valid or invalid, and to determine the most prevalent sustainability methods and processes being used in the industrial construction sector. In addition, information was summarized on how to implement sustainability practices and the benefits of their implementation. Economic models were also investigated that help assess the benefits of using sustainability practices on industrial construction projects. A metric was developed to help members of the industrial construction sector assess their success at implementing sustainable development practices on their construction projects.

2.9 DEVELOPMENT OF THE RESEARCH DOCUMENTS

The information that was obtained during all of the processes mentioned in the previous sections of this chapter was used to write 1) a primer on sustainable design and construction for members of the industrial construction industry, 2) an executive summary of the salient points of the primer, and 3) a research report that provides additional information on the technical aspects of the research project along with a detailed presentation of the data collection and analysis process used for the research project. This research report also provides a summary of the comments provided in the surveys.

CHAPTER 3

SUMMARY OF CURRENT SUSTAINABILITY PRACTICES IN THE INDUSTRIAL CONSTRUCTION SECTOR

3.1 INTRODUCTION

This chapter discusses sustainability practices that are being implemented in the industrial construction sector along with additional information related to sustainable development that impacts firms that operate in the industrial construction sector.

3.2 OBSTACLES TO THE IMPLEMENTATION OF SUSTAINABILITY DEVELOPMENT

In England, a study was conducted to determine what the obstacles are to implementing sustainability development practices. The study determined that there were twelve major obstacles and they are listed in Table 3.1.

Table 3.1 - Obstacles to the Implementation of Sustainability Practices in England

	Barrier to Implementing Sustainability Practices	Incidence of barrier
1	Sustainability measure was not considered by stakeholders	By far the most commonly recorded barrier
2	Sustainability measure was not required by client (includes purchasers, tenants and end users)	Commonly recorded
3	Stakeholder had no power to enforce or require sustainable measure (in some cases it was the responsibility of the client or the contractor)	Commonly recorded
4	One sustainability measure was forgone in order to achieve another (traded)	Commonly recorded
5	Sustainable measure was restricted, or not allowed, by regulators	Commonly recorded
6	The sustainability measure cost too much (in some cases the investor would not fund)	Commonly recorded
7	Site conditions mitigated against the use of a sustainable measure	Commonly recorded
8	Inadequate, untested or unreliable sustainable materials, products or systems (including long term management problems)	Commonly recorded
9	Sustainable measure was not available	Commonly recorded
10	An unsustainable measure was allowed by the regulator or statutory undertaker (so no impetus for a sustainable alternative to be used)	Infrequently recorded
11	Stakeholder was not included, or was included too late, in the development process to implement sustainability measure	Infrequently recorded
12	Stakeholder lacked information, unawareness or expertise to achieve sustainable measure	Infrequently recorded

Source: Williams, K; and Dair, C., 2007, *What is Stopping Sustainable Building in England? Barriers Experienced by Stakeholders in Delivering Sustainable Development*, **Sustainable Development**, Vol. 15, No. 9 pp. 135-147.

3.3 SUSTAINABILITY GLOBAL REPORTING INITIATIVE

According to the study that was conducted in England the most commonly recorded barrier to implementing sustainability practices was that they were not considered by stakeholders; therefore, stakeholders would need to provide the impetus for firms to consider implementing sustainability development practices (Williams, 2007). In order to address this issue the Global Reporting Initiative (GRI) was started in 1997 and it includes globally applicable guidelines on how to report sustainability achievements (PriceWaterhouseCoopers, 2004; Global Reporting Initiative, 2002).

Sustainability reporting is performed using a voluntary process to summarize environmental performance on a wide range of sustainability issues. The Global Reporting Initiative helps companies to “quantify current impacts, formulate targets for development, and communicate with customers, communities, governments, financial markets, and other stakeholders about sustainability issues” (Andrews and Slater, 2002). The GRI guidelines “are not a substitute for legally mandated reporting or disclosure requirements; they do not override legislative or regulatory requirements. The aim of the GRI guidelines is to assist reporting organizations and their stakeholders in articulating and understanding the contributions these organizations make to sustainable development” (PriceWaterhouseCoopers, 2004).

Global Reporting Initiatives are used to inform stakeholders about the environmental accomplishments of a company so that stakeholders are able to make more informed decisions. For example, in the energy utilities industry some companies are using their earlier experience with environmental reporting (which included reporting harmful effects on the environment) to prepare sustainability reports. Many of these reports are formulated based on the *Sustainability Reporting Guidelines* of the Global Reporting Initiative (GRI), released in June of 2000 (Global Reporting Initiative, 2002).

The GRI was developed by members of several international organizations such as the Coalition for Environmentally Responsible Economics (CERES), the United Nations Environment Program (UNEP), private companies, governmental agencies, non-governmental agencies (NGOs), and members of academia (PriceWaterhouseCoopers, 2004).

Over 2,000 companies throughout the world, including over one-third of the 250 largest companies list in the Global Reporting Initiative (GRI), have issued numerous environmental reports (Andrews and Slater, 2002). Table 3.2 provides some examples of the industrial firms that are included in the *Dow Jones Sustainability Group Index* (DJSI) and whether they have published a *Sustainability Development Report* (SDI).

Table 3.2 Dow Jones Sustainability Group Index and Sustainability Development Reports (March 2008)

	DJSGI	SDI
3M	Y	Y
Abbott	Y	Y
The AES Corp.	N	N
Air Products and Chemicals, Inc.	N	Y
Alcoa	Y	Y
Amgen, Inc.	Y	N
Anheuser-Busch Companies, Inc.	N	N
Aramco Services Co.	N	N
BHP Billiton	Y	Y
Biogen Idec, Inc.	N	N
BP America, Inc.	N	Y
Cargill, Inc.	N	Y
Chevron	N	Y
CITGO Petroleum Corporation	N	N
Codelco-Chile	N	Y
ConocoPhillips	Y	Y
The Dow Chemical Co.	Y	Y
DuPont	N	Y
Eastman Chemical Co.	N	Y
Eli Lilly and Co.	N	Y
ExxonMobil Corp.	N	Y
GM Corp.	N	Y
GlaxoSmithKline	Y	Y
Intel Corp.	Y	Y
International Paper	N	Y
Kaiser Permanente	N	N
Kraft Foods	Y	N
Marathon Oil Corporation	N	Y
NOVA Chemicals Corp.	N	Y
Ontario Power Generation	N	Y
Petroleo Brasileiro S/A - Petrobras	Y	Y
Praxair, Inc.	Y	Y
The Procter & Gamble Co.	Y	Y
Progress Energy, Inc.	N	Y
Rohm and Haas Co.	N	Y
Sasol Technology	N	Y
Shell Oil Co. (Royal Dutch Shell)	Y	Y
Smithsonian Inst.	N	N
Solutia, Inc.	N	Y
Southern Co.	N	Y
Sunoco, Inc.	N	Y
Tyson Foods, Inc.	N	Y
US Steel	N	Y

Source: Dow Jones Sustainability Group Index, 2008, <http://www.sustainability-indexes.com/> and individual company web sites.

In 2007, Gary Hirshberg, the owner of Stonyfield Farm, launched a nonprofit firm that provides a ranking of major corporations on 22 criteria related to sustainability including “carbon footprint, reducing emissions, and supporting progressive climate legislations” (Underwood, April 14, 2008). A companion website, called ClimateCounts.org, includes the criteria and rankings.

The United Nations International Declaration on Cleaner Production has been signed by members of over 1,000 organizations including government agencies, firms, business associations, nongovernmental organizations, academic institutions, professional societies, and international agencies (Basu and Van Zyl, 2006). The most important elements of management involvement identified in this document are (Basu and Van Zyl, 2006 p. 302):

- Corporate commitment.
- Integrating environmental management systems with general corporate management systems.
- Selecting a core team with detailed knowledge covering all the business units, which can in turn involve the entire workforce.
- Environmental cost accounting to identify and monitor total environmental costs in parallel with other costs facing the operation.
- Structured and proven methodology for implementing cleaner production, including assessment of environmental benefits and cost savings as well as communicating these assessments.

The results of a survey that was conducted in 2007 by McKinsey and Company included responses from 391 chief executive officers (CEO) from all over the world who work for firms that participate in the United Nations Global Compact. The respondents indicated the following (Sullivan, March 2008 p. 55):

- 95% - CEOs who said society has greater expectations than it did five years ago.
- 90% - CEOs who said they are doing more than they did five years ago to incorporate environmental, social, and governance issues into their core strategies.
- 72% - CEOs who said companies should incorporate a stance on environmental, social, governance issues in strategies and operations.
- 50% - Executives who said their companies actually do incorporate such a stance.

3.3.1 Global Reporting Profiles

In order to generate global sustainability reports members of firms need to include the following information (PriceWaterhouseCoopers, 2001 p.1):

- Decisions on application of GRI principles.

- Criteria/definitions used for accounting for, and measuring, sustainability costs and benefits.
- Significant changes in measurement methods.
- Assurance policies and practices including management systems, processes, audits and management reviews to ensure accuracy, reliability and completeness.
- Policy and practice for independent assurance/verification of report and actions contained therein (i.e., did they do what they said they did?).
- Means by which users can obtain additional information, including country, region or facility specific information.

3.3.2 Corporate Structure Governance

When a firm is planning to develop a GRI its members should first identify (PriceWaterhouseCoopers, 2001 p. 1):

- Major committees of the Board that have responsibility for setting corporate strategy and that have oversight responsibilities, and the process used to determine their competencies to provide input on sustainability strategy.
- The percentage of Board members that are independent, non-executive directors.
- The Board level processes for identification and management of enterprise-wide risks and opportunities.
- Linkages between executive compensation and achievement of sustainability objectives.
- Organizational structure of the groups assigned primary responsibility for sustainability governance, and their alignment with strategy and policy, objectives and identified risks.
- Mission and values statements, guiding principles, core values, codes of conduct/ethics, policies relevant to sustainability performance and status of implementation.
- Mechanisms for minority shareholders to provide opinions and input to management and the Board.

3.3.3 Contents of Global Sustainability Reports

According to the *Global Sustainability Reporting Guidelines* that are part of the Global Reporting Initiative the following items should be included in sustainability reports (PriceWaterhouseCoopers, 2001 p.1):

- The organization's approach to enterprise wide risk management, including the application of the precautionary principle.
- Externally developed, voluntary economic, environmental and social charters, sets of principles, or other initiatives that the organization subscribes to or endorses.
- Memberships in industry associations and national/international advocacy groups.
- Supply chain management as it pertains to outsourcing and supplier sustainability performance, and product and service stewardship initiatives.
- Approach to managing indirect sustainability impacts resulting from its activities.
- Decisions regarding opening or closing of new plants and expansions/contractions.
- Management systems, programs and procedures, including planning, implementation, checking and acting elements for continuous oversight and improvements in sustainability performance.
- Registration or certification of sustainability management systems, such as ISO 14001, OHSAS 18001, and SA 8000.

Global sustainability reports usually provide information that is matched against company objectives, license requirements, or other relevant industry statistics (PriceWaterhouseCoopers, 2004). Firms may also include performance evaluations for their subcontractors and vendors in global sustainability reports.

3.3.4 Core Sustainability Indicators

Examples of core sustainability indicators are the following (PriceWaterhouseCoopers, 2001 p. 1):

- Water use.
- Total materials use other than water, by type.
- Percentage of materials used that are wastes from sources external to the organization.
- Direct and indirect energy use by primary source.
- Location and size of land owned, leased or managed in biodiversity-rich habitats.

- Impacts on biodiversity.
- Greenhouse gas (GhG) emissions.
- Use and amount of emission of ozone-depleting substances (ODS).
- Other significant air emissions (oxides of nitrogen, oxides of sculpture and persistent organic pollutants).
- Total amount of waste by type and destination.
- Significant discharges to water by type.
- Dates, amounts and reporting of significant spills of chemicals, oils and fuels (total number and total volume).
- Significant environmental impacts of principal products and services.
- Percentage of products that is reclaimable and percentage reclaimed.
- Incidents of and fines for non-compliance with international conventions, and national, regional and local environmental legislation and regulations.

3.3.5 Social Performance

In the GRI there are only four areas identified as key performance indicators of social performance and they are (PriceWaterhouseCoopers, 2001 p. 1):

- 1) Labor Practices and Decent Work
- 2) Human Rights
- 3) Society
- 4) Product Responsibility

One study, *Developing a Framework for Sustainable Development Indicators for the Mining and Minerals Industry*, by Azapagic (2004) discusses the importance of having a sustainable mining and mineral industry where specific indicators for metallic construction and industrial minerals are developed and that may also be suitable for some energy minerals. The research outlines economic, environmental, social, and integrated indicators that could be used to detect “hot spots” and report sustainability and stakeholder involvement. The indicators developed within the framework of having a sustainable mining, metals, and mineral industry are similar to the indicators proposed by the Global Reporting Initiative (GRI) that allow having identical corporate reports and cross-comparisons (Azapagic, 2004)

3.4 SOCIAL AND COMMUNITY IMPACT OF PROJECTS

When construction projects are being built there are both social and community impacts that negatively affect the area surrounding industrial construction project job sites. According to Gilchrist and Allouche in the article *Quantification of Social Costs Associated with Construction Projects: State-of-the-Art Review* the “Types of adverse impacts associated with construction activities are grouped under four headings: traffic, economic activities, air and water pollution, and damage to the physical environment. Potential impacts as a result of unregulated construction activities include: traffic congestion and delays, disruption of economic activities, excessive generation of pollution and pollutants, damage to sensitive ecosystems, and damage to existing structures and infrastructure systems” (Gilchrist, 2005 p. 91). Table 3.3 shows a breakdown of potential impacts and social cost indicators that are associated with construction activities.

Table 3.3 Impacts and Social Cost Indicators Related to Construction Projects in Urban Environments

Traffic	Economic Activities	Pollution	Ecological/Social Health
Prolonged Closure of Road	Loss of Income	Noise	Surface/Subsurface Disruption
Detours	Productivity Reduction	Dust	Damage to Recreational Facilities
Utility Cuts	Loss of Tax Revenue	Vibration	Treating Compromised Physical/Mental Health
Loss of Parking Spaces	Property Damage	Air and Water Pollution	Reduced Quality of Life
Additional Fuel Consumption			Restoration Cost
Travel Delay			
Increased Traffic Accidents Rate			
Accelerated Deterioration of Roads			
Road Rage			

Adapted from: Figure 2. Breakdown of Potential Impacts and Social Cost Indicators with Construction Activities. Gilchrist, A.; and Allouche, N.; 2005, *Quantification of Social Costs Associated with Construction Projects: State of the Art Review*, **Tunneling and Underground Space Technology** Volume 20, p. 91.

A *social cost indicator* could be defined as a “measurable cost that can be quantified in monetary terms and is a result of one or more construction-related adverse impacts on the environment surrounding a construction site. When applying valuation method(s) to quantify a given social cost indicator the contributions of all relevant

adverse impacts should be considered. Social cost indicators can be classified into three main groups, namely: traffic, economic activities and ecological/social/health systems". Table 3.4 provides a list of the valuation methods for adverse impacts and social cost indicators.

Table 3.4 Valuation Methods for Adverse Impacts and Social Cost Indicators

Loss of Productivity
Human Capital
Replacement Cost
Lane Closure Cost
Hedonic Pricing
User Delay Cost
Contingent Valuation Technique

Source: Adapted from Figure 3. Relationships Among Impacts, Social Costs indicators and Valuation Method. Gilchrist, A.; and Allouche, N.; 2005, *Quantification of Social Costs Associated with Construction Projects: State of the Art Review*, **Tunneling and Underground Space Technology**, Volume 20, pp. 89-103.

3.4.1 Calculating the Loss of Productivity Due to Adjacent Construction Projects

The area surrounding construction projects may be negatively impacted by construction activities and some of the impacts include (Gilchrist and Allouche, 2005 p. 93):

- Loss of income
- Productivity reduction
- Reduction in tax revenue
- Property damage

Loss of productivity (LOP) could be estimated using the formula (Gilchrist and Allouche, 2005 p. 97):

$LOP1 = (\text{number of employees affected}) \times (\text{average hourly output; } \$/h) \times (\text{productivity reduction factor}) \times (\text{project duration; } h)$

The impact to property values during a construction project could be estimated using the following formula (Gilchrist and Allouche, 2005, p. 98):

Property prices = (property variables; neighborhood and accessibility variables; environmental variables)

3.4.2 Calculating User Delay Costs

User delay costs and average traffic delay costs due to construction activities could be quantified using a method introduced by Gilchrist and Allouche (2005, p. 101):

User delay costs is a method used to evaluate the total amount of time for delays that the users experience due to reduced speed through construction areas or when traffic demand exceeds capacity due to

congestion in the affected areas. A basic estimate of user delay costs utilizes a percentage of the average hourly wage, typically between twenty-five percent and thirty-three percent, and multiplies it by the average traffic delay (h) and the number of persons impacted. The value attributed to an hour of time depends on its various uses (i.e. work versus leisure).

User delay costs could be represented by the following equation (Gilchrist and Allouche, 2005 p. 99):

Average user delay costs (\$) = (average # of passengers per car) x (average delay per car) x (average hourly wage) x (% of wage)

The average traffic delay cost can be calculated based on project duration, AADT value, the peak hour factor (k), number of passengers per car and the average hourly wage.

Average traffic delay cost (\$) = (AADT) x (k factor) x (lane closure duration) x (average user delay costs, \$)

3.4.3 Global Impacts Caused by Industrial Construction Projects

One social concern related to construction projects is the loss of soil and agricultural lands. Land is lost: 1) through the quarrying and mining of raw materials since quarrying and mining adds 20 percent to the global land loss of about one and a half million hectares per year lost to urbanization, 2) when forests are used for timber production, as one-third of the forests lost are used for wood for construction projects, and 3) when creating energy for producing construction materials, and 4) when energy is consumed during construction projects. Pollution is generated by construction activities when materials are produced for construction and by the construction processes that pollute water and the atmosphere. According to the article, *Sustainable Development and the Construction Industry*, additional environmental consequences of construction operations are the following (Spence and Mulligan, 1995 p. 280):

- Erosion of the global soil base, reducing the world's capacity for food production as populations rise.
- Loss of forests and wild lands leading to loss of biodiversity, threat to indigenous cultures, and degradation of slopes and watersheds.
- Accumulation of pollutants and greenhouse gases in the atmosphere, leading to local hazards to soils, vegetation and human health, and the threat of global climate change.
- Air pollution from the emission of dust fibers and toxic gases such as nitrogen and sculpture oxides during building materials production.

In the European Union, the European Community has already formed working groups that are addressing issues related to sustainable development. Table 3.5 shows the three issue areas that are of concern in the European Union related to the construction industry.

Table 3.5 European Union Sustainability Issues Related to the Construction Industry

Issue	Brief Rationale
Environmentally friendly construction materials	Up to 50% of all materials extracted from the earth are used for construction materials including energy in use and when they are installed in a building they account for 40% of all energy use. These materials account for 50% of all waste generated prior to recovery.
Energy efficiency in buildings	Construction, operation, and demolition of facilities consumes 40% of all energy and generates similar amounts of greenhouse gas emissions.
Construction and demolition waste management	Construction and demolition wastes constitute the largest waste stream by weight in the European Union.

Source: The European Commission Enterprise, 2001b, *Proposals for a Response to the Challenge of Sustainable Construction*, **The European Union**, Brussels, Belgium www.ec.europa.eu/enterprise/construction/suscon/finrepsus/sucop2.htm, November 2007.

One method for addressing sustainability issues during construction projects was introduced by the *European Commission and Member States* and it suggests that firms should “assess tenders on the basis of the *economically most advantageous tender* (EMAT) balancing price, quality, and life cycle costs, for which the quality assessment criteria should include sustainability factors” (European Commission Enterprise, 2001b p. 1).

3.4.4 Assessing Direct Social Impacts of Construction Projects

This section discusses some of the studies that were conducted to determine the social impacts of construction projects on surrounding communities.

3.4.4.1 Noise and Particulate Pollution Impacts

One study was conducted in Beirut, Lebanon at construction job sites that were close to residential neighborhoods, and that were disturbing local residents, especially during periodic construction activities that sometimes lasted up to months or even years. In the Lebanese study one type of disturbance that was caused by construction sites was additional traffic (trucks and heavy machinery) that were emitting toxic particulates into the atmosphere and also causing noise pollution. In the Lebanese

study during the early construction phases, such as the excavation and erection phases, more particulates were released into the air than in the later construction stages (Lebanese Environment and Development Observatory, 2001).

Another disturbance was the high sound levels that were emitted by trucks, pile drivers, and during the drilling and blasting of rocks. During some construction activities the noise levels were up to 100 dBA when measured 15 meters away. Table 3.6 shows some of the average noise levels that were recorded during the Lebanese study for each construction phase.

Table 3.6 Noise Levels for Five General Phases in Construction

Phase	Noise Level (dBA) 15 meters	Noise Level (dBA) 30 meters
Ground cleaning	83	77
Excavation	85	79
Foundation	86	80
Erection	82	76
Finishing	83	77

Source: Lebanese Environment and Development Observatory (LEDO), September 2007, *Lebanon State of the Environment Report*, Ministry of the Environment, Beirut, Lebanon.

3.4.4.3 Eco-System Encroachment

Additional sources of community impacts that are discussed in the Lebanese study include eco-systems encroachment, which takes place when the boundaries of construction project job sites exceed the limits of the job site and damage local ecological systems. In some instances construction projects are built on land that was previously farmland and this also disrupts the ecological systems that existed when the land was being used for agriculture (Lebanese Environment and Development Observatory, September 2007).

3.4.4.4 Use of Unauthorized Landfills

In some areas the demolition wastes that are created when an existing structure is being removed in order to build new projects are left along roadsides in unauthorized landfills that continue to be used during construction. The contents of the unauthorized landfills impact both members of the local community and construction workers if any of the demolished materials contain toxic chemicals. Samples of toxic materials include lead, chromium, asbestos, and petroleum products.

3.4.4.5 Environmental Impacts of Construction Operations

Table 3.7 provides a description of some of the environmental impacts of construction during different phases that is from the article *The Environment in France*, which was written by the French Institute for Environment (IFEN, 1999). Table 3.7 represents all types of construction including: industrial, residential, commercial, heavy highway, and building construction.

Table 3.7 Environmental Impacts of Construction

Environmental Impacts	Description	Potential Impacts on Air	Potential Impacts on Water	Potential Impacts on Soil and Cover
Extracting raw materials	Sand and gravel	Particulate emissions	Water courses near quarries are altered	Landscape degradation
Manufacturing building materials	Cement Production	Particulate emissions CO ₂ , SO _x , and NO _x		Taking up new areas of land
Construction buildings	Transporting materials. Building sites.	NO _x and CO ₂ emissions		
Using buildings	Energy consumption, water consumption, and wear and tear of materials	CO ₂ emissions. Asbestos fibers, indoor radon emissions	Wastewater discharge containing detergents and organize matter	
Demolishing buildings		Noise and particulate emissions		Demolition waste put in landfills or reused for sea reclamation

Source: Adapted from: French Institute for the Environment (IFEN), 1999, *L'environnement en France - Edition 1999 (The Environment in France)*, **The French Institute for the Environment**, Paris, France.

3.4.4.6 Construction Waste Generation

Waste generated from construction and demolition activities including the renovation of old buildings, accounts for approximately 32 percent of all waste generated in Western Europe. The generation of construction and demolition waste in Western Europe was increasing during the 1990s (Stenis, 2005). Table 3.8 contains a breakdown of the main types of construction wastes in Western Europe and Table 3.9 shows the percentage of waste for each construction subcategory.

Table 3.8 Breakdown of Main Waste Fractions in Western Europe

Fraction	Weight (tonnes)	Breakdown (%)
Unpainted wood	2	1.9
Combustible material	34	32.4
Scrap iron	7	6.7
Cast concrete	14	13.3
Pure gypsum	12	11.4
Waste to assortment and deposit	36	34.3
Total	105	100

Source: Jan Stenis, 2005, *Construction Waste Management Based on Industrial Management Models: A Swedish Case Study*, **Waste Management Research**, Vol. 23 p. 14.

Table 3.9 Combined Percentage of Construction Wastes in Western Europe

Sub component	Breakdown (%)
Electrical sub-contractor	1
Heating and plumbing sub-contractor	1
Ventilation sub-contractor	1
Painting sub-contractor	1
Floor sub-contractor	1
Trabeation (gables including gypsum wallboard for facades)	5
Framework; cast concrete	20
Framework; reinforcement	5
Larch Panel and minerit (Swedish) material	30
Mineral wool; wet materials and spillage	15
Gypsum wallboard inner walls	10
Miscellaneous	10
Total	100

Source: Jan Stenis, 2005, *Construction Waste Management Based on Industrial Management Models: A Swedish Case Study*, **Waste Management Research**, Vol. 23 p. 14.

3.5 RESPONSIBLE SUPPLY CHAINS AND PROCUREMENT PRACTICES

Some firms are requiring that their vendors and suppliers sign a statement that indicates that they will follow the policies of the firm that is buying their products on *ethics, safety, environment, and social responsibility (SESR)* or to demonstrate that they have a similar company policy (Ofori, 2000 p. 196).

3.5.1 Supply Chain Management

The features of the implementation of *supply chain management* include (Ofori, 2000 p. 198):

- Conclusion of long-term contracts between parties.
- Willingness among the parties to learn more about each other's business operations.
- Exchange of information on business plans and operations, as well as best practices among the parties.
- Involvement of suppliers in the customer's product development and design processes.
- Commitment of the supplier to pursue continuous improvement by monitoring technological trends.
- Reducing the supplier base.
- Continuous development of supplier by the customer.
- Development of trust among partners, with suppliers taking full responsibility for the quality of their products, leading to the elimination of inspections of supplied products.

3.6 RESOURCE EFFICIENCY - REDUCING ENERGY CONSUMPTION DURING CONSTRUCTION

The area where the most energy is consumed in the area of industrial construction is during the generation of construction building materials. Producing fly ash asphalt requires 57 percent of the total energy consumed by construction projects, cement consumes 25 percent, and the remaining processes consume 18 percent. Transporting materials consumes between 15 and 30 percent of the energy consumed at job sites (Moroueh et al., 2001).

In order to reduce energy consumption during construction several strategies have been recommended in the article *Sustainable Development and the Construction Industry* including (Spence and Mulligan, 1995 p. 281):

- Improved energy efficiency in kiln processes.
- Using cheaper or non-premium fuels in kiln processes.
- Use of recycled materials in production processes.
- Use of low-energy additives or extenders.
- The use of less materials.
- Selection of low-energy materials and structural systems.
- Design of low-rise buildings in place of high-rise buildings.
- Selection where possible of waste or recycled materials.
- Design for recycling, long life and adaptability to varying requirements.

It is estimated that eight to 20 percent of the emissions generated throughout the world are due to construction activities and building materials production and approximately three percent of emissions are due to the production of cement and lime. Some suggestions provided by Spence and Mulligan for helping to reduce atmospheric pollution during construction include (Spence and Mulligan, 1995 p. 283):

- Reducing avoidable transportation of materials.
- Improving site management efficiency.
- Reduction of the quantity of site wastes produced.
- Systematic separation of all unavoidable construction wastes, to facilitate recycling.

Some methods that are being implemented throughout the world to encourage reduction in the generation of pollution caused by construction activities include (Spence and Mulligan, 1995 p. 283):

- Carbon taxes.
- Mineral extraction taxes.
- Landfill waste charges.
- Increased royalties for timber extraction from forests.
- Fines or charges for pollution.

In 2005, the *Strategic Forum for Construction* identified four areas where energy consumption could be improved at construction sites (Strategic Forum, 2005):

- Design
- Transport
- Stockholding
- More efficient use of on-site labor

During the design phase the Strategic Forum recommends that (Strategic Forum, 2005 p. 1):

Design professionals need to be more aware of the part they play in ensuring good logistics, particularly at the scheme design stage. Logistics will be greatly helped if the design professionals draw up a Process Map at an early stage in the design. In addition as part of the Logistics Plan for the project, a Bill of Materials should be prepared. This should look at, for example, the flow of materials needed on a project and ways of minimizing stockholding. Which of the professional members of the supply chain should be responsible for this, needs to be discussed, but the quantity surveyors with their background in measurement and costing might have the appropriate skills for this; alternatively it could require the input of logistics specialists. Manufacturers, suppliers and distributors clearly need to make an input to this plan.

The Strategic Forum also recommended that (2005 p. 1):

- Design professionals prepare a Process Map for each project as part of the Scheme Design.
- The professional institutions representing the design professions develop advice and offer briefing to members on the role they have to play in project logistics.
- The professional team needs to prepare a Bill of Materials as part of the Logistics Plan.
- The professional institutions consider ways in which the role of their profession in project logistics can be incorporated in initial education and training.
- Main contractors prepare a Logistics Plan in consultation with the rest of the Supply Chain at the outset of each project. This Plan should include the input to the project from the specialist contractors and the key manufacturers and suppliers.
- Construction Industry Training Board (CITB) Construction Skills review the need for logistics skills in the industry and recommend what needs to be done to address this.
- Key manufacturers, suppliers, and distributors input to the Bill of Materials being prepared as part of the Logistics Plan for each project.
- Manufacturers, suppliers, and distributors reflect the cost of distribution in their pricing policies

In the transportation area the inadequacy of logistics was an area that was investigated by the Strategic Forum and the following was determined (lorries are trucks) (Strategic Forum, 2005 p. 1):

- A high proportion of lorries in the construction industry move around the road network either empty or with part-loads, whereas the retail sector and wider manufacturing industry are continually working to consolidate delivery loads to maximize vehicle fill, and reduce transport costs.
- Many lorries arriving at construction sites are having to wait to gain access or be unloaded, whereas retail and other sectors designate time slots for supplier deliveries. Late or early deliveries can be turned away and suppliers charged a penalty.
- In construction, skilled craftsmen are often using their skills for less than 50 percent of their time on site. Amongst the non-skilled tasks they are involved in are unloading lorries and moving products around site. Other industrial and retail